S. HRG. 99-221

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, AND CERTAIN INDEPENDENT AGENCIES APPROPRIATIONS FOR FISCAL YEAR 1986

HEARINGS

BEFORE A

SUBCOMMITTEE OF THE

COMMITTEE ON APPROPRIATIONS

UNITED STATES SENATE

NINETY-NINTH CONGRESS

FIRST SESSION

ON

H.R. 3629

AN ACT MAKING APPROPRIATIONS FOR THE DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, AND FOR SUNDRY INDEPENDENT AGENCIES, BOARDS, COMMISSIONS, CORPORATIONS, AND OFFICES FOR THE FISCAL YEAR ENDING SEPTEMBER 30, 1986, AND FOR OTHER PURPOSES.

PART 1—(Pages 1-869)

CONSUMER PRODUCT SAFETY COMMISSION
COUNCIL ON ENVIRONMENTAL QUALITY
DEPARTMENT OF THE TREASURY
Office of Revenue Sharing
EXECUTIVE OFFICE OF THE PRESIDENT
Office of Science and Technology Policy
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NATIONAL SCIENCE FOUNDATION
VETERANS ADMINISTRATION

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DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT-INDEPENDENT AGENCIES APPROPRIATIONS FOR FISCAL YEAR 1986

THURSDAY, MARCH 14, 1985

U.S. SENATE,
SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10 a.m., in room SD–192, Dirksen Senate Office Building, Hon. Jake Garn (chairman) presiding.

Present: Senators Garn, Leahy, and Proxmire.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

STATEMENT OF JAMES M. BEGGS, ADMINISTRATOR

ACCOMPANIED BY:

- **JOHN MARTIN, ASSOCIATE ADMINISTRATOR FOR AERONAUTICS AND SPACE TECHNOLOGY**
- **ROBERT O. ALLER, ASSOCIATE ADMINISTRATOR FOR SPACE TRACKING AND DATA SYSTEMS**
- **BURTON I. EDELSON, ASSOCIATE ADMINISTRATOR FOR SPACE SCIENCE AND APPLICATIONS**
- **C. THOMAS NEWMAN, COMPTROLLER**
- **JESSE W. MOORE, ASSOCIATE ADMINISTRATOR FOR SPACE FLIGHT**
- **JOHN SHEAHAN, DIRECTOR, BUSINESS MANAGEMENT DIVISION, SPACE STATION PROGRAM**
- **ISAAC T. GILLAM IV, ASSISTANT ADMINISTRATOR FOR COMMERCIAL PROGRAMS**
- **C. ROBERT NYSMITH, ASSOCIATE ADMINISTRATOR FOR MANAGEMENT**

OPENING REMARKS

Senator GARN. The subcommittee will come to order.

The purpose of today's subcommittee hearing is to hear testimony on budget submissions from the National Aeronautics and Space Administration. I am happy to welcome each of you here this morning, gentlemen.

Through the work conducted by NASA, the United States continues to lead the world in the exploration of space and space technology. NASA's aeronautics research has also been a major factor in our world leadership in the production of civil and military aircraft. In addition to our preeminence in space exploration, our investment in NASA also pays off as a direct stimulus to increased national productivity, especially in the areas of telecommunications and Earth resources assessment.

Other spinoffs of NASA's technology are less well known but equally important. New products are created, new markets established, and our national security has been enhanced. The space agency is truly a national resource of scientific and engineering talent that is unmatched elsewhere in the world.

For fiscal year 1986, you are requesting a total of $7,866,000,000, or $394.6 million over your fiscal year 1985 appropriation, and your R&D request of $2,881,800,000 is 19 percent over the fiscal year 1985 level.

Today we will depart from our normal hearing format by dividing the session into two parts. First, we will take testimony from Mr. Beggs and his associates; then around 11 a.m. we will ask Dr. Robert Frosch and Mr. Aaron Cohen to summarize their observations and recommendations on the subcommittee-sponsored Advanced Technology Advisory Committee study of automation and robotics.

I would also like to add, Mr. Beggs, that obviously this is your fourth appearance before the subcommittee since I have been chairman. I think it should be obvious to everyone that this year is different in some respects and I have a much greater detailed knowledge of NASA than I have ever had before in reading documents and listening to testimony in this budget submission. I have, as everyone knows, been deeply involved in Houston and the shuttle program the last couple of months.

That is not the subject of today's hearings, nor will it be. This is a regularly scheduled hearing that was set up some time ago. At that time, we had all expected that Challenger and 51E would have flown and we would have had a more extended hearing. I do expect after my flight has been completed to call you back for additional testimony to get into more specifics of my findings. But today we will just go ahead with the normal routine budget submissions and questions on NASA's request because I do not think it would be useful to pursue the other aspect of what I would like to get into this year until that has been completed and we have gone through the entire process.

DELAY OF STS-51E

I would just briefly say, however, that it has not only been a very unique experience but, obviously, it has been somewhat disappointing and frustrating to all of us because of the delays. There have been a lot of questions of me about those delays, and it has obviously brought more attention to those delays because of my involvement. I am sure I can speak for Colonel Bobko and the rest of the crew, that although we are disappointed, there are none of us that feel that anything but the right decisions have been made, specifically with the cancellation of Challenger.

I am sure you could imagine what my reaction would be as chairman of this subcommittee, or Senator Proxmire as former chairman of the subcommittee, or any of the members of the subcommittee, if a decision had been made to take a $100 million satellite into space and then found out there was prior knowledge there may be some problem with that satellite.

So there is a very distinct difference between what the crew may feel as far as some personal disappointment of not going on schedule and having a mission cancelled, but certainly no criticism of the decision. It was the only responsible decision that you could have made.

If you really wanted this subcommittee and this chairman to react, it would have been to have gone ahead and put a $100 million satellite into space and then have difficulties with it, with prior knowledge that that may occur.

So the delays are disappointing. The decisions have been proper. The personal disappointment of myself or any members of the crew is insignificant compared to the decisions that you have had to make on the basis of the expense involved and the mission of the space shuttle.

Now, I am hopeful that this last one will be able to be fixed and not cause any undue delays. I guess none of us would have anticipated with the technical complexities of the orbiter and the system that we would experience a delay from a cherry picker, something as common as that. Nevertheless, it has taken place.

So we will, as I said, defer any further discussion about the details of the space shuttle system until a later date. So I thank you for your willingness to be here today.

Before I turn to you, Mr. Beggs, I would turn to Senator Leahy, the new ranking minority member of this subcommittee, to see if he has any opening statements he wishes to make.

STATEMENT BY SENATOR LEAHY

Senator LEAHY. Thank you, Mr. Chairman. I do look forward to being the new ranking member on this subcommittee. I, of course, gave up my former assignment on the District of Columbia Subcommittee with great reluctance. [Laughter.]

Senator GARN. I did that several years ago, too. [Laughter.]

Senator LEAHY. I think every one of us has. I am reminded of the story that Senator Stennis, whom we all love dearly on this committee, told me about as a young Senator, he was assigned to that committee. Shortly thereafter, he was called down to the White House. President Truman wanted to meet with the new Senators. And President Truman came up to him and said, "Well, young man, I understand you are now a significant factor of the D.C. Subcommittee."

And Senator Stennis with great pride said, "Yes, sir. That is right, Mr. President."

And President Truman said to him, "I have some advice for you, young man."

Senator Stennis said, "What is that?"

And he said, "Get off that damn fool committee as soon as you can." [Laughter.]

So I had a feeling that, perhaps, in a subtle way Senator Stennis was giving me a bit of advice.

I am glad to be up here with my good friend, the Senator from Utah. I come here with a sense of enthusiasm. I worked with Chairman Garn on a number of issues in the past and look forward to working with him here.

I think each one of us, Republican or Democrat, on the Appropriations Committee, has become, whether we were or not when we came here, more and more fiscally conservative as we look at the budget going through again, prodded by people like my good friend Bill Proxmire and others into that sense, but we can't sit here and pass these enormous budgets without having just an automatic reaction we have to find areas of saving money and also have a conviction that the agencies must do the jobs that we in the Congress and that the President, the executive branch, has given them.

We find also within our committee that I think it is one where we have been able to work out differences probably better than just about any other committee in the Senate.

Now, of all the agencies overseen by this subcommittee, I find of great interestest to me is NASA. I am proud of America's leadership in space. I have shared that pride as a Vermonter. Vermont has the second fastest high tech employment growth in the country. Per capita base, it is one of the third or fourth highest high tech areas in the country.

I don't want to sound like the Vermont Chamber of Commerce, but everyone is allowed a certain amount of a parochialism here. Whatever you call it, Yankee ingenuity, Vermonters have had it.

But I have also watched with interest as a supporter of the space program, and I have had some very real concerns in that regard. I have been down to watch a couple shuttle takeoffs. One was scrubbed at the cost of millions of dollars to the American taxpayers because, as it turned out, one of the computers wasn't turned on early enough to match up. Another shuttle that I went down for—and I just happened to watch these two because those are the only two times I have gone to watch a shuttle take off—it didn't take off. The other one was because of a minor part malfunction from one of our prime contractors. So that for a relatively inexpensive part, again millions of dollars were lost.

I have always voted for the space program, but I am also looking at some real tight times coming up in budgets. I am going to reconsider that in the future. We will have to make sure we are getting our full money's worth.

CONTRACTOR SUPPORT FOR STS

Now, I have a lot of respect for Mr. Beggs, who is here today and is doing a superb job. I see my good friend Mr. Murphy is here behind him, who has been very, very good and responsive to the needs for information from the Congress.

But I think we he are going to have to start looking very carefully. I know I am, and I am going to ask the staff to look carefully at the budget. We are going to look carefully at some of the main contractors like Rockwell and Boeing and others. I want to find out if they screw up in a component and it ends up costing us a lot of money, who pays for it? Do the taxpayers pay for that or are we getting money out of them? They are making billions out of this. What kind of responsibility are they carrying?

I mention this with the Administrator here so that you know the kinds of questions you will be getting not so much just in this hearing, Mr. Chairman, but staff will be calling you and I will be calling and I will be checking personally on a number of these things.

With the order of the space program, I know we are going to be having to cut money, including in that program, and I want to make sure we are not cutting out the things that the country needs and have contractors continue to make money on it. So that is one I am going to be looking at very closely here as a member of this committee.

I also will be wearing—in other matters which we won't go into in these open hearings—another hat as vice chairman of the Intelligence Committee because of the importance of the shuttle. We will be looking at that, too.

But those are the things. I am very impressed with what you have done. But I am also well aware that the projections certainly for the next 5 years of the cost of the space program are, I am pretty sure, more than this country can afford. I want to see whether we can still do a great deal of the space program within a curtailed amount of money. In that regard, I want to make sure that the prime contractors are giving us all the value for what we are paying.

Thank you, Mr. Chairman.

I also look forward to working with you, Mr. Chairman.

CONGRESSIONAL COMMITMENT TO NASA

Senator GARN. I would suggest the Senator might ask me some questions, too. Not today. As I said, I have had a rather detailed, inside look. Even Mr. Beggs, as Administrator, has not had the opportunity to look at it on the level that I have looked. I would suggest that there will be some areas that I will have some suggestions in where we can, not in the spirit of trying to curtail programs, but in the spirit of trying to make them work more effectively, use those dollars more effectively.

So I will be happy to work with the Senator in using what knowledge I have gained in that particular area.

I would say, however, that one of my first committees, besides D.C., was the Space Committee, when I first came here 10 years ago. Frank Moss, my former senior colleague from Utah, was the chairman, when we had a separate space authorization committee. Jim Fletcher was the Administrator, who was the former president of the University of Utah before his tenure as Administrator of NASA.

In terms of looking at it only in terms of dollar, that entire committee 10 years ago made a commitment to NASA, although budgets were tight, that we would keep them whole for inflation at a very minimum, not any real increases but at least increases for inflation.

That promise has never been kept. So NASA has suffered real cuts over the years by not even being made whole for inflation, where many agencies of the Federal Government have not only been made whole for inflation, they have grown far beyond in terms of real growth.

Having said that, that is not to say there are not some areas where the money couldn't be better utilized within the organization. That is where I intend to look very carefully, how can we redirect some particular dollars.

I think also in the assessment, NASA is a different type of agency than the many others we deal with, even in the subcommittee. It is not a regulatory agency. It does have a collection of very highly trained, skilled professionals, engineers and scientists, probably a greater collection than any other agency, not only in our Government but in other governments around the world.

I think in our evaluation of what a total budget should be, besides trying to maximize how those dollars are used and cut out waste, and if the contractors are not absorbing enough of some of the mistakes and so on, we will have some comments about that in the future, too. But I do think we have to assess in the case of NASA to the value of the spinoffs. If we spend *x* number of taxpayers' dollars, how much does that produce in the private sector in terms of products and scientific endeavors that are used daily.

I don't think we realize how many things each of us use every day now came out of the space program. I think we have to look at that particular balance.

But if I continue to talk, I am going to disclose more than I wish to until my experience is over. I think the Senator and others on this committee, and NASA, will be pleased with some of the direction and insight that I will be able to give them.

As a matter of fact, a lot of the information that I have been obtaining during this experience has been volunteered by NASA employees who wish to have some changes and corrections made so that the dollars can be used more efficiently in the areas that they are working in.

Senator Proxmire, do you have a statement?

Senator PROXMIRE. No thank you, Mr. Chairman.

Senator LEAHY. Mr. Chairman, Mr. Beggs, the chairman and I sometimes carp back and forth. That is really where a lot of this discussion will go on. I am aware the 1980 budget, I think in constant dollars, dropped about 12 percent. We are off to looking at housing budgets going down about 40 or 50 percent. These are some of the restraints that will go on.

So I concur with the chairman very much; we want to make sure we are getting our money's worth. We are also aware of the spinoffs and also what it has done to America's prestige. But I am also aware of the fact an awful lot of companies are making a lot of money off the space program, and I am sure they do it first and foremost because of their dedication to America and a sense of patriotism. But just in case that sense of patriotism may not have gone so far as to watch out for things like cost overruns and all these things, we will look at that.

Thank you, Mr. Chairman.

Senator GARN. Mr. Beggs, please proceed.

NASA'S FISCAL YEAR 1986 BUDGET REQUEST

Mr. BEGGS. Thank you, Mr. Chairman, distinguished members of the subcommittee. It is my pleasure to appear before the subcommittee to present President Reagan's budget for NASA for fiscal year 1986.

The total NASA request is $7.9 billion, of which $2.9 billion is for research and development, including $354 million for aeronautical research and technology; $3.5 billion for space flight, control, and data communications; $149 million for construction of facilities; and $1.3 billion for research and program management.

I might add, Mr. Chairman, parenthetically, that in furtherance to your statement on keeping NASA whole for inflation, had we been kept whole for inflation in the last 10 years or since about 1973 or 1974, when those statements were made, this budget would be about $9.5 billion instead of the $7.9 billion we are asking for.

The NASA budget for fiscal year 1986 provides for solid progress toward the aeronautics and space objectives approved by the administration and the Congress. Consistent with last year's congressional endorsement of the President's space station initiative, our planning in fiscal year 1986 will proceed, but at a slightly slower pace than we had anticipated last year.

SPACE STATION

Our planning efforts will focus upon Space Station system definition and technology development and will incorporate examination of both a man-tended approach and advanced automation and robotics technologies. We hope to conclude agreements with the European Space Agency, Canada, and Japan in the near future to allow for parallel definition effort, leading to significant international participation during the development phase.

With the Space Shuttle an increasingly mature system, a permanently manned space station is the next logical step in space for this Nation to take. We look forward to beginning its detailed design and development in 1987, directed toward building this station within a decade.

OVERVIEW OF FISCAL YEAR 1986 ACTIVITIES

The space transportation system, built around the space shuttle, will continue to gain operational maturity and demonstrate new capabilities. In fiscal year 1986, we plan 14 launches carrying commercial payloads, national security missions, and NASA missions to Earth orbit and to the planets.

The Centaur upper stage will be launched from the shuttle for the first time, the first shuttle flight will be launched from Vandenberg Air Force Base, and we will begin development of an orbital maneuvering vehicle to provide a new capability for on-orbit operations.

Space science and applications will experience a banner year. Early in 1986, a special set of three telescopes, known as the ASTRO payload, will fly aboard the shuttle to make observations of Halley's Comet. In early 1986, the Voyager spacecraft will encounter the planet Uranus to give us the first closeup look at that large, unusual, and unexplored planet and then continue on its way to Neptune.

The Galileo mission will be launched in late spring of 1986. An option has been added to allow the Galileo spacecraft, while en route to Jupiter, to fly by and observe the asteroid Amphitrite. The Galileo orbiter/probe will encounter Jupiter in December 1988 where the probe will be released into the dense atmosphere of that planet while the orbiter spacecraft remains in orbit to obtain additional data on the planet and to take a close look at its satellites.

During the same planetary launch window, the Ulysses spacecraft, formerly known as the International Solar Polar Mission, will be launched toward Jupiter and will use the tremendous gravitational force of that planet to accelerate into a trajectory that will permit inspection of the Sun at high latitudes never before available for observation.

Later in 1986 the Hubble Space Telescope will be launched into Earth orbit to provide resolution far superior to that available in even the best ground-based telescopes and to provide a quantum jump in our ability to observe and understand the universe.

In addition, we will continue working aggressively on future missions, including the Gamma Ray Observatory, the Venus Radar Mapper Mission, the Mars Observer, and the Upper Atmospheric Research Satellite.

Consistent with the congressional action on the fiscal year 1985 budget, we will be pursuing development of the Advanced Communications Technology Satellite planned for launch in 1989 to demonstrate the technology needed for the United States to remain competitive in this important area.

Although fiscal year 1986 will be a vigorous year for the Space Science and Applications Program, it has been necessary to defer initiation of new projects, which, of course, will be essential to the future vitality in the space science and applications area. I believe the hiatus in fiscal year 1986 is reasonable provided we make appropriate provision for new initiatives in future years.

In late 1984, NASA established the Office of Commercial Programs pursuant to the administration's national commercial space policy. This Office will provide a focus to encourage commercial use of space. The fiscal year 1986 budget will continue and expand initiatives which began in fiscal year 1985 to stimulate research and development by aerospace and nonaerospace companies, facilitate access by private and academic entities to NASA facilities and equipment, establish new links with the private sector, and establish centers to promote the commercial development of space.

In aeronautics, the fiscal year 1986 budget focuses on research and technology activities which supply and replenish the reservoir of technology which has been the fundamental source of our Nation's preeminence in aviation. In addition to the more general and generic technology, the budget continues a carefully selected group of systems technology efforts, including the numerical aerodynamic simulation project, designed to move the United States to the forefront in the extremely complex area of computational fluid dynamics. We will also be working on the advanced turboprop propulsion systems to provide technology for a new generation of fuel efficient transport aircraft.

The budget provides for a modest growth in the space research and technology activities which are also crucial to the future U.S. leadership in space. It also provides for establishment of the fully operational three-spacecraft TDRS system.

Mr. Chairman, I am satisfied that the budget we are requesting for fiscal year 1986 is a reasonable budget considering the constrained fiscal environment in which all programs must be considered, and I am satisfied that we can and will achieve substantial progress toward all of the Nation's major objectives for which NASA is responsible.

That concludes my statement, Mr. Chairman. I would be pleased to respond to questions.

Senator GARN. Thank you very much, Mr. Beggs.

[The statement follows:]

STATEMENT OF JAMES M. BEGGS

Mr. Chairman and Distinguished Members of the Subcommittee:

It is a pleasure for me to appear before this Subcommittee to present President Reagan's budget request for NASA for FY 1986. The total NASA request is $7.9 billion, of which $2.9 billion is for Research and Development, $3.5 billion for Space Flight, Control and Data Communications; $149 million for Construction of Facilities; and $1.3 billion for Research and Program Management. The NASA budget for FY 1986 provides for solid progress toward the Aeronautics and Space objectives approved by the Administration and the Congress.

SPACE STATION

In response to President Reagan's directive of last year to develop within a decade a permanently manned Space Station, NASA has begun a major new endeavor, one that I believe will ensure United States leadership in space during the decade of the 1990's and beyond, while at the same time providing a sound framework for a mutually beneficial cooperative program with our friends and allies abroad. Progress, so far, has been substantial.

We have initiated a competition within U.S. industry for Space Station definition and preliminary design that is scheduled to commence in April of this year and lead to a thorough understanding of Space Station systems prior to hardware development. We have begun a technology development program that will enable us to incorporate the proper level of advanced, sophisticated systems aboard the Station. In accordance with the President's directive, and as a follow-up to the results of the London Economic Summit at which the attending nations welcomed the U.S. invitation to participate in the Space Station development, we have held extensive discussions with representatives of the European Space Agency, Canada, and Japan. These discussions should lead initially to their own Space Station definition studies, in parallel with ours, and ultimately to a partnership in Space Station hardware development and use.

We have established a Space Station management structure that designates the Johnson Space Center in Houston as "Lead Center" while fully utilizing the talents of other NASA installations. We have also established a strong user or customer focus to the Space Station Program, reflected organizationally in our creating Space Station Chief Scientist positions at both NASA Headquarters and the Johnson Space Center. It is reflected too in the utilization of a specially constituted Space Station Science Advisory Committee chaired by Dr. Peter Banks of Stanford University and by the emphasis we've placed upon Space Station mission requirements. Advocacy groups have been established to represent customer requirements for potential commercial, scientific, and technology development payloads and these will be incorporated in the definition and preliminary design studies that begin in the spring.

As we've undertaken these activities, we have been mindful of the directives received from Congress last year when it approved the Agency's budget request of $150 million to begin the Space Station Program. The study of a "man-tended" approach, requested by Congress, has been set in motion by its incorporation in the definition and preliminary design activity; U.S. industry will examine this option in conjunction with the main body of analysis. The Advanced Technology Advisory Committee has been established to analyze, and report to the Congress upon the potential for advancing the technologies of automation and robotics. This analysis will be utilized by U.S. industry as it conducts the Space Station definition studies.

The Station will consist of a manned base with accompanying unmanned platforms, one of which is likely to be in polar orbit. The base and platforms would be carried aloft in modular sections by the Space Shuttle which would assist in the on-orbit assembly and check-out of the Space Station. The Shuttle would also be used for logistics resupply and crew rotation. By utilizing both manned and unmanned elements, the Space Station will enjoy the substantial advantages offered by both modes of space flight. Combined with the unique advantages provided by a truly permanent presence, the Station will significantly enhance United States capabilities in space.

The Space Station will be a versatile and effective facility, serving a diverse range of functions. It will be:

- a national laboratory in space, for the conduct of science as well as the development of new technologies and related commercial products;
- a permanent observatory, to look down upon the Earth and out into the universe;
- a servicing facility where payloads and spacecraft are resupplied, maintained, upgraded and, if necessary, repaired;
- a transportation node where payloads and vehicles are stationed, processed and propelled to their destinations;
- an assembly facility where, due to ample time on orbit and the presence of appropriate equipment, large structures are put together and checked out;
- a manufacturing facility where human resourcefulness and the servicing capability of the Station combine to enhance commercial opportunities in space;
- a storage depot where payloads and parts are kept on orbit for subsequent deployment, and
- a staging base for future endeavors in space.

The Space Station will also be:

- a striking example of Free World unity and capabilities; and
- a highly visible yet peaceful demonstration of U.S. leadership.

In FY 1986 NASA is requesting $230 million for Space Station activities. During the fiscal year the Space Station definition and preliminary analysis will be under way. The advanced technology development activity will be in progress while user payload requirements will be refined and updated. In addition, a highly innovative Technical Management and Information System will be established to enhance overall program management and a Space Station operations concept will be developed. Our current schedule envisions that Space Station hardware development will begin in 1987. This schedule allows for international partners in the Space Station Program to work in step with NASA. As importantly, it enables NASA to work toward the objective of having a Space Station within a decade. From that time forward, I believe there will always be Americans living and working in space.

SPACE SHUTTLE

The President has directed that NASA's first priority is to make the STS fully operational and cost effective in providing routine access to space. He has also directed that the STS program will receive sustained commitments by all affected departments and agencies and directed that enhancements of STS operational capability, upper stages and efficient methods of deploying and retrieving payloads will be pursued as national requirements are defined.

While I am extremely proud of our record of 15 highly successful launches, I recognize that it is essential that we continue to move forward to drive down Shuttle costs and provide the opportunities for further commercialization of space so that this country can compete effectively in the international arena and maintain its leadership in space. I am concerned that we might find ourselves in the same situation in the space industry that we now find ourselves in the automobile industry. We cannot look at space launches without also looking at the long term impact on the satellite manufacturers, the upper stage industry and the other infrastructure we have built up in this country over the last 26 years. With aerospace and agriculture contributing effectively to helping alleviate our balance of payments problem it is essential that we take additional steps to ensure that these jobs are not lost to the U.S. economy.

The STS capability includes a highly competent, experienced STS team; the four Orbiter fleet - Columbia, Challenger, Discovery, and Atlantis; commercial and government upper stages, two Launch Pads at the Kennedy Space Center; the Vandenberg Launch Site; production capabilities and facilities to support 24 flights per year; and the dedication and experience to provide customers easy access to space.

At the present time two of our Orbiters, OV-099 Challenger and OV-103 Discovery, are operational, OV-102 Columbia is undergoing modifications and OV-104 Atlantis has a planned April 1985 delivery.

While the Shuttle team has an unblemished safety record, we must ensure that each mission is safe and reliable. Our planning during the next few years focuses on bringing the STS to operational maturity. This includes: essential modifications to the Orbiter fleet, improved life and operating margins on the main engines, particularly the high pressure pumps, and ensuring that an improved operational capability is in place. It is also essential that we provide increasingly efficient and customer friendly operations for Shuttle and Spacelab users. We are working with DOD to prepare for manned space operations at Vandenberg Air Force Base and the Shuttle Operations and Planning Center at Colorado Springs.

This year saw the first full year of operations at Kennedy Space Center (KSC) under the Shuttle Processing Contract and the Base Operations Contract. Both contracts continue to show increased efficiencies. At the Johnson Space Center we are planning a Space Transportation System Operation Contract to consolidate work now being performed by 16 contractors into a single contract.

Two of the highlights in the Space Program this past year which hold great hope for the future are the retrieval and repair of the Solar Maximum Mission satellite and the retrieval of the Westar and Palapa communication satellites. The Solar Max spacecraft had been launched in 1980 but was disabled by the failure of its fine-pointing system. The Solar Max repair mission enabled the satellite to resume its program of solar observations and measurements. The Westar and Palapa satellites were spectacularly retrieved on our November mission and brought back to Earth. They are currently being refurbished and we understand that the space insurance industry is in the process of reaching an agreement on their resale.

In FY 1985 we plan 10 Shuttle flights including dedicated DOD missions, Spacelab missions, the deployment of over a dozen communication satellites, and the second TDRS launch using the IUS. The third TDRS may also be launched later in 1985. 1985 will also see the completion of the upgrading of Columbia and the inaugural flight of the fourth Orbiter, Atlantis.

Our FY 1986 budget request for the Space Transportation System Program is $3160.9 billion. This supports 14 missions, or an average of one approximately every 25-30 days, with the scheduling dominated by the planetary launch window in May. Pad B at KSC will be brought into service in time to support the Galileo Jupiter launch, only six days after the Ulysses (International Solar Polar Mission) is launched from Pad A. The missions include four Spacelab flights, launch of the Hubble Space Telescope, numerous communications satellites, two flights of the McDonnell Douglas pharmaceutical pilot production module, the first flight from Vandenberg AFB, one other dedicated DOD mission, two payloads to make observations of Halley's Comet, and several materials processing payloads.

With the flight rate increasing and the Orbiter production program winding down, there is continued emphasis on Orbiter spares and the Space Shuttle Main Engine. The initial increment of structural spares has been defined, negotiated and production is underway with deliveries scheduled thru 1987. This provides a set of major structural components to be used in the event of major damage to an Orbiter, while helping to maintain a production base, and potentially reducing the lead time to build an additional Orbiter, if one should be required in the future. Since last year, there has been a major re-planning of the Space Shuttle Main Engine (SSME) Program, with a focus on limiting the scope of improvements to increase operating life and design margins of the current configuration. In addition, we are establishing an advanced development effort having two major thrusts; alternative engine contractors and a technology test bed.

Major efforts in the launch and landing area include activation and readiness of launch pad B, activation of the third Mobile Launch Platform and modifications to provide the capability to service the Centaur upper stage for the initial Centaur flights. Construction of the new Solid Rocket Booster (SRB) refurbishment and assembly facility at KSC will be completed. The fabrication of filament wound case (FWC) segments will continue and the development testing will be completed.

The Orbital Manuevering Vehicle (OMV), a reusable, remotely piloted system which represents a significant extension of capability for the Space Transportation System will be initiated in 1986 and be available for flight use in 1990.

SPACE SCIENCE AND APPLICATIONS

The Space Science and Applications program has had impressive results this past year. Some which are particularly noteworthy include the completion of the IRAS mission, the restoration of the Solar Maximum Mission, the flight of the Shuttle Imaging Radar-B and the Large Format Camera, the launch of the Active Magnetospheric Particle Tracer Explorers, Earth Radiation Budget Experiment, and a host of other first-rate scientific achievements.

The budget request for Space Science and Applications of $1613.2 million will support the continuance of a healthy and scientifically challenging program. Space Science will experience a banner year in 1986 as past investments become reality. Early in the year a special set of three telescopes known as the ASTRO payload will fly aboard the Shuttle to make observations of Halley's Comet. The Voyager Spacecraft will encounter the planet Uranus in 1986, to give us the first close-in observation of that large, unusual and unexplored planet and then continue on its way to Neptune. The Galileo Mission will also be launched in late Spring of 1986. An option has recently been added to the Galileo mission to allow for the spacecraft to fly by and observe the asteroid Amphitrite while on the way to Jupiter. The Galileo orbiter/probe will encounter Jupiter in December 1988 where the probe will be sent into the dense atmosphere of that planet while the orbiter spacecraft remains in orbit to obtain additional data on the planet and to take a close look at its satellites. During the same planetary launch window, the Ulysses spacecraft, will be launched toward Jupiter and will use the tremendous gravitational force of that planet to accelerate into a trajectory that will permit inspection of the Sun at high latitudes never before available for observation.

Later in 1986, the Hubble Space Telescope will be launched into Earth orbit to provide resolution far superior to that available in even the best ground-based telescopes and thereby providing a quantum jump in our ability to observe and understand the Universe. The Space Telescope like Galileo and Ulysses involves extensive contributions from our European partners. We will continue working aggressively on other ongoing space science and applications missions including the Gamma Ray Observatory, the Cosmic Background Explorer, the Extreme Ultraviolet Explorer, the Venus Radar Mapper, the Upper Atmosphere Research Satellite, and the Mars Observer.

The Life Sciences budget will allow continuation of work to ensure astronaut health and productivity in space. It will also support the activities needed to ensure success in establishing a permanent presence in space with the Space Station.

Our Space Applications program will be supported at the $551.8 million level. Consistent with the congressional action on the FY 1985 budget, we will be pursuing development of the Advanced Communications Technology Satellite planned for launch in 1989 to demonstrate the technology needed for the United States to remain competitive in this important area.

This funding level will allow for the continued development of the Upper Atmospheric Research Satellite and the NROSS Scatterometer as well as the critical research in solid Earth and environmental observations. We will also continue ongoing development efforts in Materials Processing and Information Systems.

Although FY 1986 will be a vigorous year for the Space Science and Applications program, it has been necessary to defer initiation of new projects. I believe the hiatus in FY 1986 is reasonable provided we make appropriate provision for new initiatives in future years.

COMMERCIAL PROGRAMS/TECHNOLOGY UTILIZATION

In support of the National Commercial Space Policy and the amended National Aeronautics and Space Act of 1958, NASA in 1984 established the Office of Commercial Programs to pursue new ways of reducing the technical and financial risks of doing business in space. The Commercial Programs Office will provide a focus for a NASA-wide program to encourage U.S. private investment in commercial space ventures and facilitate commercial application and transfer of existing aeronautics and space technology.

The FY 1986 request of $30 million for Commercial Programs will continue and expand a series of initiatives begun in FY 1985 to support the National Commercial Space Policy and to implement NASA's Commercial Use of Space Policy. These initiatives will help stimulate research and development by aerospace and non-aerospace companies; increase access to NASA's facilities and equipment; establish new links with the private sector and establish centers to provide for the commercial development of space.

NASA's FY 1986 proposal of $11.1 million for Technology Utilization will allow continued effort to transfer NASA-developed technology to U.S. industry, the public and other Government agencies.

AERONAUTICAL RESEARCH AND TECHNOLOGY

NASA is requesting $354.0 million in FY 1986 for Aeronautical Research and Technology to provide the broad technology base essential to the preservation of U.S. leadership in aviation. The program includes fundamental research in the aeronautical disciplines and a carefully selected group of focused systems research directed at the interactions of disciplines and components and the evaluation of new concepts.

Key elements in FY 1986 include the Advanced Turboprop program which is developing single- and counter rotation propeller and aircraft integration technologies for a new generation of fuel efficient aircraft. Critical technology gaps are being addressed through proof-of-concept testing of the unducted fan and flight testing of a large-scale advanced propeller in FY 1987 as directed by Corgress. In addition, the Numerical Aerodynamic Simulation Program will begin to provide the U.S. with the world's most advanced capability for numerical simulation of aerodynamic flows about an aircraft and through the rotating turbomachinery of engines. The initial system will be brought to operational status in FY 1986.

Flight research activities to explore the operating characteristics of the DARPA/NASA X-29 forward swept wing research aircraft will continue and the DARPA/NASA X-wing rotor research aircraft is being readied for first flight in early FY 1987. Similar activities are planned in conjunction with the Navy to develop an oblique wing research aircraft.

SPACE RESEARCH AND TECHNOLOGY

The FY 1986 Space Research and Technology request of $168.0 million provides for modest growth in a broad base of advanced technologies contributing to the Agency goals of improved operational effectiveness of the Space Transportation System; an efficient and productive Space Station; and to enable the United States to lead in the exploration of the solar system and observation of the Earth from space. It also supports expanding military and commercial space needs with technological options which make future space systems and applications a practical and economical reality.

Major programs in FY 1986 include: research on advanced components and diagnostic instrumentation to improve the life and performance of large LOX/hydrogen engines leading to tests in a SSME test-bed engine; vehicle and propulsion technologies directed at the critical needs for a reusable, space-based orbital transfer vehicle; automation research addressing teleoperations and robotics for spacecraft and Space Station applications; development of in-space experiment capabilities to provide the technology base for cryogenic fluid management, large thermal energy systems; and to investigate the dynamics and control of large, flexible structures. Experimentation in space is critical to the development and verification of future space systems and commercial applications and will be an important focus of the space R&T program. Significant events occurred in this area during 1984. The Long Duration Exposure Facility (LDEF) was deployed in April and is scheduled to be retrieved in March 1985. It will be returned to Earth so that the long-term effects of space exposure can be evaluated on selected materials and components. In August, an experimental, 100 foot solar array was deployed from the Shuttle Orbiter Discovery cargo bay. The array was instrumented to provide the first research data on the dynamic response of large, highly flexible structures.

SPACE TRACKING AND DATA SYSTEMS

For the Space Tracking and Data Systems Program, NASA is requesting a total of $824.5 million for FY 1986. These funds will provide for the continuation of the vital tracking, command, telemetry, communications, and data processing support to meet NASA flight program requirements. The transition of the ground tracking network to a space tracking capability for low Earth orbit missions is continuing. This transition began with the launch of TDRS-1 in April of 1983. Since the dramatic recovery from the upper stage failure, the TDRS-1 has successfully supported the various Shuttle missions, as well as Spacelab, Landsat, Solar Mesopheric Expolorer, Earth Radiation Budget Experiment, and the Solar Maximum Mission.

The launch of TDRS-2 has been deferred due to a problem in the timing circuits of the spacecraft. The extent of the delay necessary to complete the requisite spacecraft modifications and to reschedule the launch is not known at present. The required satellite constellation will be completed with the launches of TDRS-2 and TDRS-3. Full operational capability of the space network will be achieved with the completion of the required checkout and testing following the launch of the third spacecraft.

The Ground Networks, composed of the residual Space Tracking and Data Network (STDN) and the Deep Space Network (DSN), will continue to provide tracking and data support to a variety of missions during FY 1986. In anticipation of the TDRSS full operational capability, we are continuing to make substantial reductions in our ground tracking network which supports near-Earth spacecraft. The STDN is now half the size it was five years ago, and most of the remaining stations will be closed or transferred to other agencies when TDRSS becomes fully operational.

The Deep Space Network, which provides the only means of communications with our deep space and interplanetary missions, is on the threshold of an especially active and critical period. The Networks Consolidation Program is scheduled to be completed by the end of February 1985 which will permit the DSN to assume support responsibility for spacecraft above the view of the TDRSS as well as for those older spacecraft which are not compatible with TDRSS. A major DSN upgrade is scheduled for completion in the Fall of 1985 which will allow us to meet the increasingly complex mission needs.

Two major activities in NASA's Communications Program will become operational in FY 1986, both of which will employ available advanced technologies developed by the communications industry--a Time Division Multiple Access system which will provide operational circuits via satellite, and a Program Support Communications Network which will handle NASA's growing non-operational communications needs among its Centers.

CONSTRUCTION OF FACILITIES

Of the FY 1986 Construction of Facilities request of $149.3 million, approximately one-third is allocated to essential repairs, rehabilitations and modifications, and minor construction, while approximately one-half is allocated to 14 major projects in support of critical programmatic requirements. The budget provides needed facilities support for Space Shuttle operations and related activities such as the construction of an Orbiter Modification and Refurbishment Facility at KSC and modifications for an Advanced Technology Engine Test Stand at MSFC.

Three major facility projects in support of Space Science activities are also included. A Micro-devices Laboratory at JPL will provide the necessary environment for conducting microelectronics research and technology development for solid state devices, spaceborne very large scale integrated circuits, and advanced computer architecture. At Goddard Space Flight Center, the budget request will permit the construction of the initial phase of a Spacecraft Systems Development and Integration Facility. This project, when completed with a similar amount in next year's budget, will provide the capability for developing and integrating spacecraft of sizes that can exploit the full capability of the Shuttle.

Facility projects in support of Aeronautics and Space Technology include the second increment of funding required to complete the Numerical Aerodynamics Simulation Facility at Ames Research Center and modification of the 16-foot Transonic Tunnel at Langley Research Center for improved productivity and research capability.

RESEARCH AND PROGRAM MANAGEMENT

The NASA institution is appropriately sized and capable of carrying-out the FY 1986 program. In the FY 1986 Research and Program Management Budget, there are, however, two significant changes from FY 1985; first, the salary rate for civil service personnel is five percent lower in FY 1986 than FY 1985. This reduction in salary rates is part of the Government-wide reduction directed by the President beginning in 1986. The other major change has been a reduction of 200 civil service FTE's and $21.0 million related to the President's drive to reduce administrative costs in the Government. We will endeavor to accomplish the reductions in a manner to minimize the impact on program accomplishment. The balance of the changes in R&PM reflect a constant level of operations at expected price levels.

Mr. Chairman, I am satisfied that the budget we are requesting for FY 1986 is a reasonable budget considering the constrained fiscal environment in which all programs must be considered and I am satisfied that we can and will achieve substantial progress toward all of the Nation's major objectives for which NASA is responsible.

TDRSS FAILURE

Senator GARN. First let me ask one question that does not relate to your general testimony or statement. That is concerning the cancellation of Challenger due to TDRS.

The only question I have there—and as I said very emphatically to begin with, I do not question the decision at all that the mission should have been cancelled. The question I do have for you relates to the fact that TRW apparently had knowledge of a problem with the existing TDRS-1 at the end of January.

So my question is simply if they thought there was a problem, why did it take so long, go all the way through mating the TDRS on Challenger, being essentially ready to launch within a week, and then have the decision to cancel made? Would it have been possible for TRW to advise NASA earlier there was a problem before it got so far down the line?

Mr. BEGGS. If they had understood the problem, Mr. Chairman, I think the answer to your question would have been, "Yes, it would have been possible." But there was in the January–February time period an indication, if you will, a clue that such a problem might exist.

We and TRW immediately tried to duplicate that particular anomaly in the simulation equipment we had. We could not do that. That is, neither NASA nor TRW could find that a problem existed. So, we took it that this was an anomaly which does occur from time to time in space systems of this complexity and did not think that we had a major issue.

After we were on the pad and had started to do the final preparation of the satellite the problem came to light in its full magnitude, if you will. We went back to the laboratory again and were able to simulate that anomaly completely. We found that we had a high probability of a significant failure if we went ahead and launched. So with that knowledge in hand, it became impossible, of course, to launch. The prospect of having two satellites in orbit, which could at some future time become inoperative, was just an unacceptable risk.

We did not understand the full magnitude of the problem and, in fact, we are still doing some laboratory tests of the system to assure ourselves that the various fixes that we are proposing to integrate into the spacecraft are sufficient to obviate any future problem.

Senator GARN. Again, I don't disagree with the decision, but you feel there was no way of making it earlier, the information simply was not adequate enough to make the decision earlier?

Mr. BEGGS. The information was, as I say, in the nature of a clue. Had we been smart enough at that time, perhaps we could have done somewhat more. But, we did not have the data that would have led us to the conclusion that we had a very high probability of outage. As I say, that came up as we were preparing for launch.

I think, at least my review of this, that we did exercise due diligence. We did our best to try to uncover the problem in the laboratory environment and were unable to do it.

Senator GARN. I don't only ask that question as part of that mission but as to the impact it has on the downstream launches through the rest of the year. Obviously, the sooner the decisions can be made, the less impact it has on all of the scheduled missions and the manifests throughout the rest of 1985.

Mr. BEGGS. Yes, sir. It concerns us a great deal, because in looking at the flight rate that we are trying to achieve, both this year and the buildup that we will have to achieve this year in order to achieve our flight rate next year, we don't want to lose a flight. Obviously, we have lost one and that hurts. We think we can recover from it adequately. But we would just as soon not have had it.

I can assure you that we have tried to broadly apply, if you will, the lessons we learned from this. I do hope, and I believe that both our contractor and ourselves are more sensitized to exercising our systems more completely and trying to get on top of problems in advance of any launch state. That will not obviate, obviously, some similar problems because some of the equipment we buy is clearly state of the art. We will, no doubt, run into things like this from time to time, but I hope we will be able to recover.

ELV TURF BATTLE

Senator GARN. Mr. Beggs, one of my pet peeves the entire time I have been in the Senate is turf battles within the Federal Government. They exist over and over again between various agencies, regardless of who the President is. Regardless whether it is a Democrat or Republican President or administration, We find competing interests within the same administration and also between various agencies.

That appears to be true with the Air Force and the ELV. Now, this is a discussion that has gone on for some time. I certainly do not have any dispute with the need for a backup to the shuttle by using expandable launch vehicles. The Air Force recently awarded a $5 million contract for preliminary development work on a new configuration of the Titan missile capable of launching shuttle-class payloads. This involves two missiles at a rate of two per year begining in 1988. At the same time, the Air Force has committed to utilizing one-third of the shuttle launch capacity.

It was not only my own concern about the Air Force wanting to maintain their own capability to resurrect some old Titans, which I am personally not still convinced is a good thing to do. Apparently the Air Force has never given up, never changed their mind, never really seriously considered a launch vehicle with growth capability or the willingness to look at an enhanced SRB, shuttle-derived, so that we were saving money and yet still developing a backup vehicle.

The more I have studied this, I am still not convinced that the Air Force is right. It appears to be more of a turf battle, that the Air Force wants to run their own programs and resurrect an old missile. I am not a scientist or engineer, but I am not convinced that this so-called reconfigured Titan is anything but an old Titan with some new hubcaps on it—that is obviously oversimplifying it—which my colleague says will probably fall off. He is probably correct. [Laughter.]

So I was prepared to continue to do battle with the Air Force over that. I put some language in last year that prohibited them from going ahead and ordered an additional study. We have not yet received that study. But it appears an agreement has been made between NASA and the Air Force.

First of all, what is the status of that study? Then if you could explain to the subcommittee the basis of the agreement with the Air Force and why NASA felt it either good or bad, or whatever your opinion, to go ahead and allow the Air Force to proceed with revitalizing some Titans.

ELV STATUS

Mr. BEGGS. I will try, Mr. Chairman.

There is nothing in that agreement, as it was drawn, that is any different from previous testimony that I have given on this issue. The Air Force was in a posture where they felt they had to make a decision with respect to the backup launch capability that they felt they needed. I again say that, and I said that many times. They need backup launch capability. They have to have backup launch capability. Only they can determine that requirement. They felt they had an urgent need to proceed because they have requirements for that in 1988, late in 1988. Therefore, they asked to get together with NASA to see whether we could come to some agreement with respect to the future use of the shuttle and with respect to the potential use in the future of higher lift capability, based perhaps on shuttle-derived technology or possibly other technology.

So, we wrote down essentially what had been agreed upon earlier, which is that they would go ahead and acquire 10 ELV's of capability sufficient to back up the shuttle that will, I believe, by their current decision, be a larger type, which will be augmented with a seven-segment solid. That will, indeed, allow them a backup shuttle. The agreement says that they will buy no more than 10, and that for the future, NASA and the Air Force will enter into a study looking at two things. One is the potential of follow-on manned, civil-manned vehicles—that is a follow-on shuttle—and heavy lift ELV capability. We are in the process of getting that study initiated.

In addition to that, the agreement says that the Air Force will use up to one-third of the capacity of the shuttle to a total capacity of 24 a year, or 8 per year, that they will fill. They, in turn, will agree to pay for that on a basis which, we feel, will put an incentive on the Department of Defense to use the shuttle. That is, they will pay an up-front fixed cost for that one-third of the capacity and then they will pay per flight on the basis of marginal cost. So we will agree on a total cost and we will divide it into two segments, one of which will be paid at the beginning of each fiscal year as a fixed charge and then, as they fly, they will pay the additional incremental cost of flying on the shuttle. That will give them ample incentive to fly that eight flights a year, because on that basis, once they have paid the up-front fixed charge, it will be cheaper to fly on the shuttle than any other means.

I believe the agreement is mutually advantageous. It allows NASA to plan its budget for the shuttle in a more stable environment. It gives the Air Force the assurance both of primary supply of shuttle capability and of the backup capability they needed.

Obviously, as I have stated many times in the past, we would have liked to have seen the Air Force use shuttle-derived technology for the future ELV. That is not totally out of the question. However, under this agreement we will initiate a study for the purpose of defining what the heavy lift capability requirement will be and how we will satisfy that using the best technology that we have available.

Obviously, the best technology we have available at the current time is the shuttle-derived technology. That is the most modern that we have. It doesn't obviate looking at what might be available in the early nineties, and we will do that as well.

With respect to the study that was ordered by the Congress, it is complete. I thought that it was on its way up here. I received a copy on my desk, I think, the day before yesterday. I thought that it was up here.

The congressional requirement lays the prime requirement for that study on the Air Force. NASA is, of course, a participant and we signed off on the joint study. But it is the Air Force that will submit the study. I thought it was on its way up.

CHAIRMAN'S POSITION ON NASA/AF AGREEMENT

Senator GARN. I haven't seen it yet. Maybe I could get a copy of Aviation Week and read it there before I get my original copy. [Laughter.]

Let me just say I don't necessarily fault the agreement that has been made, and it probably is mutually advantageous to both sides. Let me be clear about my position.

I think that this primarily started out and has continued to be a turf battle by the Air Force. I say that as a retired colonel in the Air Force and having something to do with them over the years and being rather favorable to most of their activities. But I don't think they like being out of the space business.

It seems to me a waste of resources to start reexamining this issue. We have a space agency. It seems to me they ought to be in the space business and that we shouldn't be spending taxpayers' money for turf battles.

I happen to wear another hat. I happen to also be a member of the Appropriations Subcommittee on Defense. When the Air Force comes around we are going to talk about this in more detail and why they feel they need to stay in the space business or be in the space business. I think a lot of it is turf and control. They don't want to have to talk to a civilian agency to talk about their launches and so on. They want to have their own little toys. Those little old Titans are rather expensive toys.

I suppose the thing that bothers me more than anything else, other than that they are old and we are going to spend money to change them somehow, is they don't have any growth potential. When we in government are spending taxpayers' money to fix up old things that are very temporary in nature, I don't think that is a good expenditure of money. Whether that should be an advanced SRB, shuttle derived, certainly from a general concept it makes sense to take the latest technology and try and improve it rather than old technology and try and improve it.

But even if it weren't shuttle derived, I don't know why we are spending money on something that has no growth potential for the future, particularly when we have limited dollars.

I am talking to the wrong side of this. NASA, I am sure, would agree, if you could, in the inner sanctum of these turf battles, that you believe it would make more sense to continue in one direction rather than spinning off. So I don't know whether it is the Navy that wants their own launch capability in the future. Maybe the Army needs some, the Coast Guard. I don't know. Maybe Congress ought to have our own launch vehicle for orbiting things into space. [Laughter.]

But it seems to me that it is not wise. I haven't even seen the study yet, but as you can tell, I have a biased viewpoint. That is why I put the language in last year and had a lot of conversations with the Air Force trying to get them away from their bias. So even if the agreement is good, the Air Force has never gotten off what they said they wanted to begin with. Regardless of studies, regardless of scientific advice, they want their own little program and their own little ballpark.

So we will talk to them about it in another committee and see how long, with limited dollars and seeing a lot of pressures on the defense budget and freezes and things of that nature, that I don't happen to agree with, but nevertheless, in an era of tight budgets, the Air Force might decide there are better ways to go than creating their own little space agency.

My time is up. Senator Leahy?

BENEFICIAL USE OF SPACE

Senator LEAHY. Mr. Chairman, I have always been impressed that NASA is a mission agency. A couple of things on what you were saying earlier.

To me, a mission agency has a clear goal of where it wants to go and the resources it needs to get there. I think one of the basic missions, of course, of NASA is to develop the beneficial use of space. When I hear the debate on space commercialization, I become concerned the agency's mission is going to get lost in the political morass.

I hope we are going to continue to give NASA the mission to develop commercial uses of space and allow it to make the policy decisions it needs to help make the commercial use of space more profitable.

Mr. Beggs, I would appreciate it if you or your staff may want to send me a letter or memo on just what steps you do to make sure that you are able to keep doing it, because I think that is important. Certainly it is important to the nature of NASA and to why NASA was set up in the first place.

[The information follows:]

COMMERCIAL USE OF SPACE

During the recent HUD-Independent Agencies Appropriations Subcommittee hearing on NASA's fiscal year 1986 budget request, you requested information on steps NASA is taking to encourage the commercial use of space. Forwarded herewith is an overview of NASA efforts to expand the level of private sector investment and involvement in civil space and space-related activities.

Congress recently amended the NASA Space Act of 1958 directing the agency to "seek and encourage . . . the fullest commercial use of space." On July 20, 1984, the administration announced a National Commercial Space Policy that was developed to reduce the technical, financial, and institutional risks of doing business in space. In support of these actions, and of an agencywide goal to expand the level of private sector investment in space, NASA established the Office of Commercial Programs and issued the NASA Commercial Use of Space Policy.

NASA's fiscal year 1986 funding budget request supports the commercial use of space in two broad areas: Commercial development and technology utilization. All of the proposed fiscal year 1986 budget for commercial development ($30 million) and technology utilization ($11.1 million) will be directed toward research and development and related activities.

The fiscal year 1986 funding request of NASA's Office of Commercial Programs was developed to strengthen the research and development foundation that will stimulate industry-funded commercial product development. To expand the amount of NASA research with commercial space applications, and increase the commitment of industry resources to commercial space endeavors, the following fiscal year 1986 commercial space initiatives have been proposed: Centers for the commercial development of space; stimulating NASA research with commercial potential; stimulating private sector commercial research; and increasing the availability of NASA facilities and equipment.

NASA's efforts to stimulate private investment in space are directed at space and space-related technology which holds the greatest economic promise. The commercial space market sector with the greatest market potential is the microgravity research sector.

NASA has identified a number of primary research areas utilizing the unique attributes of space which may lead to commercial space ventures, including electronic materials and biotechnology.

STUDY OF ACID RAIN ON FORESTS

Let me go into another specific area and one I was discussing in Vermont yesterday when I was up there. Last year your agency, in cooperation with the University of Vermont, began what I think is a pretty exciting project. I think it is going to produce critical information concerning the effect of acid rain on our forests. It is one of these spinoffs of NASA and a spinoff of our whole space program.

The project as specially designed promotes spectrometers to determine what is happening to our forests. I think it is an exciting thing because it can simultaneously do a number of things. It can collect data on the nature of forest damage, whether caused by acid rain, metal pollution, or drought. It can tell the extent of forest damage using remote sensing from aircraft and ultimately, I guess, from the space station. It can survey vast areas, the areas determined only by the altitude of what is being used for the survey. It can ultimately survey nationwide. It is projected to be a 3-year project.

I am just wondering, is the agency going to be going back to Vermont to complete the second phase of this project, does anybody know?

Mr. BEGGS. Yes, sir; we will continue to pursue this with the university. The activities we have ongoing are in two of our centers, Goddard right here outside of Washington and out of JPL in Pasadena, CA.

As you noted, Senator Leahy, we are working with the university to use a number of different types of sensors to look at the forest in a number of different ways across a fairly broad frequency spectrum. The purpose of that is to allow us to study in some detail the way in which forest land, in the case of Vermont the spruce forest, gets under stress for various reasons. If we can understand that, then we will be able from our space centers to maintain a continuous monitoring of the forest lands to determine at any time when you have a stress developing—as you noted, either from acid rain, heavy metal pollution, or other reasons of disease or stress in forest lands.

We are using a number of instruments on the airborne side, and we, of course, are using and will continue to look at the use of the thematic mapper we have in operation on the land side to correlate with these airborne instruments as well. We are trying to establish ground truth with equipment on the ground in Vermont. We will continue to pursue that project as long as it gives us useful results. So far, we are far from having plumbed the depths of that research. It is a terribly expensive program because we are using existing capital resources, but I think it is one that could have some very broad application to forest lands and other areas.

Senator Leahy. So you think if you are able to prove its value in what is a relatively small area, then this is something that may be done from the shuttle later on for a much larger area?

Mr. Beggs. Yes, sir. We are flying a series of microwave instruments in the shuttle that go by the terminology "shuttle imaging radar." These instruments are very interesting in that they extend your reach into higher and higher frequencies and allow us then to look more fully across a broader spectrum, forest lands, cropland, and others. We will be doing that several times in the coming 2 years.

Senator Leahy. I am glad to see it being done. I am glad to see the experiment in Vermont, not just because of our acid rain problem, obviously, but I can just see the application nationwide based on that. Please keep me informed as you go along with it because it is something of great interest to me.

I find in preparation for the committee assignment that I go around the State and find the amount of shuttle work going on in Vermont, it is remarkable, but this one especially because of its nationwide application.

I have used my time. I am going to have some other questions on followup, Mr. Chairman. I yield to my colleague from Wisconsin.

Senator Garn. Senator Proxmire?

INTERNATIONAL PARTICIPATION IN SPACE STATION

Senator Proxmire. Thank you, Mr. Chairman.

Mr. Beggs. Maybe Mr. Sheahan wants to help answer this question, too. In your opening statement you referred to agreements you hoped to reach with the European Space Agency, Canada, and Japan to allow for a parallel space station definition effort, leading to significant international participation during the development phase.

How much do you expect other countries to invest in this definition effort?

Mr. Beggs. The European Space Agency countries are planning to spend something over $2 billion in current dollars. At the ministers meeting in Rome a month or so ago, they agreed to provide a budget——

Senator Proxmire. Mr. Beggs, my first question is about the definition effort. The $2 billion you refer to would cover more than the definition phase.

Mr. Beggs. Excuse me. The European studies will run about $65 million. The Japanese studies will run about $20 million to $25 million. The Canadian effort is probably about the same, at $20 million or $25 million. That will carry them through phase B.

We expect that they will initiate those studies about the same time that we initiate studies which are coming up very soon, the first of April or so. We are drawing a memorandum of understanding with all three of these entities to provide a framework that will allow us to exchange information.

Senator Proxmire. I don't want to take anything for granted, but I assume the participation of these other nations in the definition effort will reduce our cost.

Mr. Beggs. No, sir.

Senator Proxmire. It won't reduce our costs at all?

Mr. Beggs. No, sir.

Senator Proxmire. If they didn't participate, the definition phase would cost us exactly the same amount of money?

Mr. Beggs. It was the intent to invite participation from Europe, Japan, and Canada on the basis they would supply things that were unique to them. So, it would be an additive cost to the amount of money we would spend.

Senator Proxmire. Would that be true also of the development expenditures of $2 billion?

Mr. Beggs. Yes, sir.

Senator Proxmire. Their participation would not produce any economies in our budget?

Mr. Beggs. No. Obviously, the Europeans, Japanese, and the Canadians will enter this program with the intent of achieving some advantage, both economic and otherwise, for themselves. We will define the station as we go along in such a way as to provide for specific pieces that will be advantageous for them to develop and produce.

Senator Proxmire. Then is it a fair conclusion that none of the total $8 billion cost of building the space station, will be paid for by other countries taking part in the project?

Mr. Beggs. That is correct, Senator Proxmire. Of course, we will end up with a significantly larger station and much more capable station than otherwise.

Senator Proxmire. But the additional capability will not be for our principal advantage but for the advantage of other countries?

Mr. BEGGS. The principle under which we are developing our agreements is that the station will be considered as a whole and that each party will, with appropriate payments to cover the lease cost and rental cost of the facilities, be allowed to to use once the station becomes operable.

Senator PROXMIRE. Is it fair to say then that our overall capital costs would be $8 billion while other countries would pay $2 billion? That means we would be putting in 80 percent of the costs.

Mr. BEGGS. $8 billion by ourselves and $2 billion by the European station nations which, incidentally, is oversubscribed right now, $1 billion by the Japanese and upward of $200 million to $400 million by the Canadians. So another $3.5 billion.

DEFINITION PHASE OF SPACE STATION

Senator PROXMIRE. You are requesting $230 million in fiscal year 1986 for a definition program leading to the construction of a space station. The Congressional Budget Office, in preparing its outyear current services budgets, did not include the space station in its current policy base. That means, of course, that CBO felt the Congress had not yet irrevocably committed itself to construct a space station.

At what point do you think that commitment will have been made? In other words, when will we have passed the point of no return?

Mr. BEGGS. Fiscal year 1987 will be the first year we will be requesting funds for the actual development and production of the station. Our efforts over the next 2 years will be in the definition effort. The Congress will, of course, in the fiscal year 1987 budget deliberations, have before them the results of our study.

Senator PROXMIRE. So that next year, calendar year 1986, the 1987 budget year, will be the year of decision; is that right?

Mr. BEGGS. That will be the year we decide on the configuration and will request, I am sure, of the Congress the right to proceed with the authority to proceed with the development and production of the station.

Senator PROXMIRE. You told me that our expenditures for the space station construction will be about $8 billion. Other countries will contribute about $3.5 billion. How much will it cost each year to operate the station, and how much of that cost will be borne by the United States?

Mr. BEGGS. That is one of the things we are going to try to pinpoint in our phase B studies. As a ballpark estimate, right now, I would guess in the order of $400 million to $500 million a year would be the operating cost.

OTA SPACE STATION REPORT

Senator PROXMIRE. As you know, the Office of Technology Assessment [OTA] came out with a report on the proposed space station in November. The report concluded that there is no necessity for committing at this time to the specific technical concept proposed by NASA, the related time scale, or the currently suggested method of funding. Do you agree?

Mr. Beggs. Yes. We have not committed at the moment and will probably not commit for another year and a half to a followup configuration. There is no necessity.

The Congress did request of us, require of us I should more properly say, last year that we look at other concepts; for example, increasing the input of automation and the techniques that probably will be available in this time period to make the station more highly automated and more productive. We have done that. Dr. Frosch will report on that today.

We will continue to look at things like that over the next 20 to 21 months and then we will come forward with a final configuration.

Senator Proxmire. OTA also said that the space station could become an end in itself, influencing the Nation's civilian space program for decades to come, rather than a means to achieve objectively important program goals. How do you react to that criticism?

Mr. Beggs. I guess my feeling on the space station is that it is another in what has been a series of steps that we have taken in our space program which opens options. It is not an end in itself in the sense that it becomes something that will exist without further objectives and further willingness on the part of the country to continue its space exploration exercise.

The station allows you to do a lot of things that you cannot now do. My assumption is that this country will continue to want to explore. In that regard, the station will serve as a staging base. It will allow you, for example, to design and produce true spacecraft instead of having spacecraft that we now have to launch and they have to withstand the shock of that launch and they also, if you want to get them back, have to withstand the heat and shock of reentry. You will able to design them in the true environment of space. We will also start to operate our facilities on a more or less permanent basis which should save money in the long run in our ability to do the research in space because we will be able to replace wornout components or components that malfunction. We will be able to replace subsystems with updated instruments as more modern instruments become available.

We are now starting to look at those more permanent facilities. The station will make that possible and easier to do. So in a number of different areas, the station is an enabling mechanism and allows us to do things that I think we will want to do as we move on.

Senator Proxmire. If the chairman will permit me, I have one more question.

According to OTA, few of the space station's proposed activities have been sharply defined or have gained wide acceptance as important objectives of the space program. Wouldn't it make sense to sharply define generally accepted space station goals before proceeding with construction?

Mr. Beggs. Yes, sir. We are doing that. We have a number of user groups, including one on science, looking at the potential of the space station and the uses that they would put it to.

In the phase B studies as well, one important part of those phase B studies will be more sharply defining the user requirements and the many things that we expect will be done'

I might add, parenthetically, Senator, that in the last year, as the idea has matured a little bit in people's minds, more and more potential uses have come to light. I think the science community, in particular, is now becoming enthusiastic about the possibilities.

I think as we get deeper into the studies and we do exactly as the report suggested, and that is to sharpen our objectives on it and to more clearly define what it will be used for, that you will see more and more of the groups who are involved in America's space program become more enthusiastic.

Senator PROXMIRE. I assume that space station goals will be defined before we are expected to make a final decision on space station construction next year.

Mr. BEGGS. Before you will have to act on the first year's funding, it will.

Senator PROXMIRE. My time is up. Thank you, Mr. Chairman.

CONGRESSIONAL CONCERN ON SPACE STATION

Senator GARN. Senator Proxmire, in response to some of your questions on the OTA study, I don't think it was too difficult for OTA to come up with that assessment. When they did, all they had to do was talk to the House and Senate Appropriations Committee, Congressman Boland and I, because the questions that you asked are the very questions we started asking some time ago, because the President made a speech and he said we are going to put up a space station. Both Chairman Boland and I, whom you know is my counterpart and used to be yours on the House side, said, "Well, that is fine. What kind of a space station? What are you going to do with it? What is it going to have in it? How is it going to function?"

So that is exactly why the second part of this hearing this morning. We fenced off in the 1985 appropriations bill money for the space station that could not be spent until this study was completed. So the questions you asked are valid. OTA was a little bit behind the power curve for once and the congressional oversight committees were ahead of some others, because the questions you asked are valid, and NASA has been responding. We certainly would not attempt to make any decisions until those questions are answered.

The concept of the space station I agree with. But one of the principal things we had proved and one of the principal disputes I had with NASA last year was that we have proved we can put men into space. I am certainly no engineer. Neither is Congressman Boland. We couldn't make a determination of where that dividing line between automation and robotics and the man-tended station is. We thought there are enough good minds around to make that determination. Because just to put an expensive space station up there to have men go back and forth to play in it is not sufficient. I don't mean to minimize the role of man.

But also to push the frontiers of robotics with that space station, so that you can have a station that needs men at times and other times it could provide useful data and information on an automated basis and you wouldn't necessarily have to have men on board. That is exactly what we are trying to determine. Dee Huddleston, who was ranking minority member, was also very much involved in that.

So I want to assure you that those questions will be answered or there won't be any approval from this or the House subcommittee until we do have satisfactory answers to those questions of exactly what we want it to be, what we want it to accomplish, what it will produce in the future. Because it would be foolish to put it up there as an end unto itself. It must be another part of the continuing advance of space travel, and it is an important piece in this advancement for the operation of the shuttle, to take the engineers and the scientists back and forth to the station.

So your questions are valid, and I assure you we will see that they are answered. Mr. Beggs knows they will be answered or money will be cut off again, as it was this particular fiscal year, to get more of those answers. That always is a very effective tool. If you take their money away from them, you get answers. [Laughter.]

IMPACT OF $50 MILLION OMB REDUCTION

Let me follow on a little bit on that, Mr. Beggs. NASA is requesting $230 million in fiscal year 1986 for space station activities. It is $50 million less than your request to OMB.

What will be the effect of this reduction upon your phase B space station definition and preliminary design studies?

Mr. Beggs. Mr. Chairman, we have lengthened those design studies by about 3 months to 21 months. It will have some impact on the IOC date. We are not sure how much, but we are going to try to minimize that effect. However, the major effect is to lengthen the current phase B contract time by 3 months. I think within the amount of money that we have that we will be able to do a very good job. It was very interesting to observe in this competition process how much interest there is in the space station in the industry. I feel confident that we will get a substantial contribution, if you will, from the industry, in addition to the money we spend.

Senator Garn. I suppose an example of interest and one that is very eminent is Charlie Walker's second flight into space with electroferesis.

Mr. Beggs. Yes, sir.

SHUTTLE FLIGHTS IN SUPPORT OF STATION

Senator Garn. I have talked to him about that and how much more interested they would be in having the time to continue that, rather than 5 to 6 days in space, the limitations of the shuttle. The electroferesis experiment even requires taking the galley out of the orbiter in order to have that space.

So a lot of the shuttle customers with firsthand experience are intereted in being able to do those experiments in a larger environment over a much longer period of time than can be accomplished in the shuttle now.

You indicate the transport of the station manned base and unmanned platforms in modular sections is to be made by the shuttle. Do you have any estimate of how many shuttle flights are required and over what period of time these flights would take place?

Mr. BEGGS. Our current estimate is about seven flights over a 6- to 9-month period to assemble it completely. We think we can handle that adequately within the manifests that we will be running in that time period. We are aiming to be flying 24 times a year in that time period. So we think that perhaps two orbiters will be required in the effort during the time period, the most intense period, of activity. But no major impact on the other shuttle manifest requirements.

Senator GARN. Do you feel you can handle 24 flights a year with four orbiters?

Mr. BEGGS. I have my mind improved almost every day, Mr. Chairman. The problems we have encountered here recently are worrisome. I try to keep those problems in perspective.

We have been flying now, well, we are going into the fourth year now, and we are learning. We have learned, I might say, an awful lot.

I am very encouraged by some of the things that we have done in this program. For example, late last year, as you know, Mr. Chairman, we flew one a month for 3 months with two orbiters actively in operation. So with that kind of experience, I think it gives us some confidence that we can indeed achieve one flight every 2 months with an orbiter. That would add up with four orbiters to 24 a year. Indeed, I think we can improve on that. I think we probably could launch one every 6 weeks, once we get to the point where we have mastered the art of turning them around and have the various subsystems to the point where they achieve the durability that we have been designing into them.

The setbacks we run into from time to time are discouraging. I sometimes wake up in the middle of the night and say, "Golly, where are we?" But I am satisfied with our progress to date. It is very good progress. If we achieve the flight rate increases over the next 2 years, I believe that we will be in good shape to fly that 24 a year with four orbiters.

As I have said before—and I guess everyone else who has commented on this agrees—it would be nice to have a backup orbiter, fifth orbiter. But quite frankly, with the flight rate that we have anticipated in the out years, it is pretty hard to justify the expense of a fifth orbiter. We haven't been able to do it.

FIFTH ORBITER

Senator GARN. I am not here to try to make that decision today one way or another, but isn't it true that to achieve that flight rate without a fifth orbiter you are going to have to have a more aggressive spares program for the four orbiters that are flying or that will be flying?

Mr. BEGGS. Oh, yes. The spares problem has nagged us for quite some time because of the problems we have run into from time to time having to go in and cannibalize to continue to get spare parts. That continues to be a problem, although we are achieving a fairly high in-stock situation. It just inched up over 90 percent here in the last month or two. We have not cannibalized any of the orbiters which are in service, at all, in the last 6 to 9 months. We have, however, had to go back onto the production line and pull some subsystems and components off the production line in order to keep our in-service vehicles flying.

I do think we have an aggressive spares program going right now. It is producing spares in reasonable quantity. We are looking again at the ongoing problem that we will have in spares once the production line shuts down completely; that is, with setting our logistics base up so we can directly procure the pieces and parts and subsystems that we will need.

Senator GARN. When do you anticipate *Columbia* will be back in service?

Mr. BEGGS. It looks like July now, with the problem that we ran into with tiles late last year, which set us back on *Columbia.* We will get *Atlantis* very soon. I think probably in the next month or 6 weeks we will have *Atlantis.* So we will have all four by the middle of the year.

Senator GARN. Senator Leahy?

RELIABILITY OF SHUTTLE

Senator LEAHY. Thank you, Mr. Chairman.

Somebody made a comment to me the other day that they compared the introduction of nuclear technology to power generation as a similar analogy to the shuttle program. I think nuclear powerplants were projected to operate around 70 percent capacity. Your capacity has been around 55 percent, or about 20 percent below design capacity. Even in the NASA area, the payload assist modules worked successfully 18 times straight and suffered 2 straight failures.

Do you think that the shuttle might not suffer similar reliability problems?

Mr. BEGGS. No, I don't, for several reasons. The payload assist modules [PAM's], are single-string systems. We ran into an unforeseen—I say we. NASA does not contract for the PAM's directly. That is one example of commercialization. They are sold directly by the manufacturer to the spacecraft owner. But the technology that is in them is clearly technology which NASA has helped to push to this point.

We did run into a single point failure on those PAM's that caused us two failures in a row. We should not have had two failures in a row. We should have only had one and we should have brought the other one back. But the owner of the second satellite chose to fly in the face of great uncertainty. Of course, we had the two failures.

The shuttle is a vehicle which has been designed with a very high degree of redundancy. Every one of our subsystems is at least triply redundant and in some cases they are quadruply redundant. Obviously, when you fly human beings in space, you want to be sure that you have an operational system.

But the advantage of that, with respect to reliability and durability, is that you can indeed continue to fly even though you are experiencing troubles on one component or another. And indeed we have had a number of those in the past year or so.

Now, the experience we have had in the last 2 or 3 months has been aggravating and irritating and frustrating, but it is not serious. By that I mean that the tile problem weran into is a problem that we understand. It was something that occurred by reason of a process that we had put in which turned out to be the wrong process. We could not foresee that. But we will learn more as we go along.

NRC ASSESSMENT OF LAUNCH RATES

Senator Leahy. Mr. Beggs, don't leave the impression it is not serious, as you are saying, because you are still posting a certain number of launches a year. You said that if the launch numbers slip, then you are going to have to—military payloads get first priority. Then you raise serious doubts about the commercial viability of the shuttle.

The National Research Council report on assessments of constraints in space shuttle launch rates identifies a number of deficiencies they say could restrain the four orbiter flights to as little as 17 flights per year.

What is NASA doing to overcome those deficiencies? Do you agree with those reports? Because that drops you 7 below the 24 flights per year level. It is certainly going to change a lot of the considerations that certainly all of us, when we look at it, whether sitting on the Defense Subcommittee, the Intelligence Committee, or whatever else. It raises some very real questions.

What do you think about that report?

Mr. Beggs. I don't completely agree with the report. I think some of the assumptions in it are a little bit flawed. But, we are taking the report seriously and are working on each of the issues that have been raised there.

The NASA Aerospace Safety Advisory Panel likewise raised some issues to us that they felt could be serious constraints to flight rate. We are working on those.

I firmly believe from the experience we have had these first 3 years on the shuttle that as time goes on, this system will become very reliable. If you look at the history of aviation over time, you will be struck by the fact that the first production models of any new transport aircraft or military aircraft has a high aeronautic rate. But as you get experience with the systems and learn how to fix them, the reliability and durability of the equipment goes up and soon you have no further problem. The early jet transports, for example, had an excessive down time. But, in a matter of just a few years, they were flying transcontinental with great reliability and the engines on those transports were experiencing very high mean time between overhauls.

The shuttle is a flying machine. The way you learn about flying machines, at least in my experience, and I spent most of my life in this industry, is that you fly them. You fly them until something breaks and then you fix it. That is what we are doing on the shuttle.

SHUTTLE FLIGHT RATE

Senator LEAHY. There is nobody in this room who questions that. That is sort of a self-evident thing, that you have problems when you first fly, and your history on aircraft reliability is something that we are all well aware of.

The point of my question, of course, though, is not that. We are not here looking at a budget to determine 20-some-odd years ago how many flights we could expect from a 707 or something like that. We are looking at budgets based on NASA's projections of the number of flights it is going to be able to make per year. Based on that, we determine how much we are going to give them as a commercial payback, how much the military can use it, whether any of us get involved in these turf fights between the military using the Titans or using the shuttle, or whatever.

Is your 24 flight per year thing unrealistic when you consider the fact it does take a while to work it up? Is it unrealistic? During the next 12 months, will you have 24 flights?

Mr. BEGGS. Well, the first year we are projecting a 24-a-year rate is 1989.

Senator LEAHY. Will you do it in 1989?

Mr. BEGGS. I believe we will, yes, sir. I think we are on that track.

Senator LEAHY. During the next 12 months, how many flights do you project?

Mr. BEGGS. In the next 12 months I think we are projecting 11, in the next 12 calendar months.

Senator LEAHY. You will make the 11?

Mr. BEGGS. I believe we will now, yes, sir.

Senator LEAHY. Thank you.

Thank you, Mr. Chairman.

COMPLEXITY OF SHUTTLE

Senator GARN. I will just comment on that getting back to a little firsthand experience, having been through the last 2 or 3 months on a rather intimate basis of looking at this.

I think the thing we have to realize in trying to project these rates, and I think it is valid, when you compare it to commercial aviation, except the comparison stops when you look at how much more complex it is—I have flown a lot of sophisticated airplanes but never anything quite on the order of this particular orbiter. There are four general purpose computers [GPC's] of 64K each which use 40 percent of their capacity monitoring the other computers to see if they are staying together. So you have freon loops, ammonia loops, you have no heaters in the orbiter; cooling is a problem. So the payload bay doors open and they have the freon loops which are to disburse heat in the spacecraft. The redundancy of systems is something that I have never seen in any aircraft that I have ever flown.

The questions are certainly valid about the flight rate. Yet, in my experience, having tested aircraft over the years that were very simple by comparison, the initial problems we had with them and failures from hydraulic pumps to you name it; simple systems we knew very well, placed in a new aircraft, didn't work properly and you ended up changing them and changing subsystems over and over again. Normally you end up spending 3 or 4 years longer than you had anticipated.

Even some of our finest aircraft, like the 707, which became a workhorse, if you went back and looked at the development phase of the 707, which became the absolute DC3 of the jet age, or the 727, there were problems. So when you add to that the complexity of an orbiter that has all the redundancy of the systems, that is launched with over 4 million pounds of fuel in a matter of 8 minutes and 37 seconds, the main engine cuts off when you are in orbit, and you operate as a spacecraft, and then return with no power through the atmosphere, interface at 400,000 feet, start a landing approach 9,000 miles from touchdown, and no mistakes to be made, no go-around, no throttles there—I don't even know why you put gear down indicators on the landing gear, Mr. Beggs, because it ain't going to make a bit of difference whether that gear is down or not. [Laughter.] You are going to land someplace when you come back in. So knowing whether the gear is down really does not make a great deal of difference. There is no power to go around.

But it is an incredibly complex system. As much as I thought I knew about aviation, I marvel that the thing even flies. I marvel we have gotten 15 of them into the air in 4 years, because 4 years ago we sent John Young and Bob Crippen in something that had never been flown before and didn't know whether it would come back or not.

So you can look at both sides. There are a lot of critics out there. Boy, have I heard them, "Oh, they will never meet the 24 a year." I don't know whether they will or not, Pat. I really don't. I don't know whether that is possible with four orbiters. It may be overly optimistic to do that. The 11 next year may be overly optimistic. I don't know the answer to that question yet.

But I really think that we ought to look at what the space shuttle will accomplish, what it will do for us in terms of future space, what it returns in the way of spinoffs. And look at the amazing technological achievement of the American scientific community to be able to put such a vehicle into space and bring it back. So you can look at it either way.

If you look at it in that way, I am surprised that they have been able to get as many of them off as they have, particularly in the last 6 months, with *Atlantis* not being finished and *Columbia* being totally retrofitted.

PUSHING STATE OF THE ART

Senator LEAHY. Jake, nobody questions that. My point and the point I want Mr. Beggs to understand is they come in and say here we have gone back, we have assessed this and all, we can only fly 2 next year or 11 or 18 or whatever it is.

I think the shuttle is a technological marvel. I have said so many a time. My concern, though, is as one who has to vote on money, both for the shuttle and for a whole lot of other programs. So I just want to know how many times it is apt to go up.

I commend NASA for their commitment to safety. Certainly it is something that the Soviets have never emulated in their space program. It is a remarkable record. It is a remarkable record of achievement.

My purpose in asking these questions is simply to try to get the best answers possible, to project what you are going to do, because that is going to determine how I vote on some of your requests and on a whole lot of other requests, in this and other committees. And to do that, I have to get the most accurate answers.

You would do a disservice to us and to yourselves if you came in with an overly optimistic thing. We don't want you just to come down and hedge all of your bets, of course not. Here is a thing where we are pushing the frontier in every way possible. But I am looking for the most accurate answers possible because that determines do we build another shuttle? Can we do the space station? Can we do a lot of other things? Can we get the commercial payback? And how do we answer those people in the military who want to use Titans and so on?

I am cutting into other people's time. I don't mean to. But I just want to make it very clear, the chairman very well knows the purpose of my questions, but I want to make clear to Mr. Beggs the purpose of those questions. We are out here looking for places to find money. I want to be in the best position possible in making those choices.

Senator GARN. I certainly understand the purpose of your questions. They are valid questions. They are questions that these gentlemen are asked every year before this subcommittee as we have progressed.

My only comment was to indicate that it is a difficult thing to judge those launch rates and to be able to—like I say, I don't know. I don't know whether they can get 24 a year. I think a year from now, based on the experience of having four orbiters, that question will be much easier to answer with precision because they are trying to operate with a limited fleet when four of them are operating.

I think Mr. Beggs will be able to come back next year with a great deal more confidence and we will have a great deal better feeling whether those are accurate. We obviously have to adjust our budgeting to what that rate is.

Mr. BEGGS. If I could add, Mr. Chairman, it is not only four orbiters, it is the fact that in a year we will have three launch pads whereas we only have one now. That is going to make a profound difference in our ability to plan our way into that higher launch rate. Operating on one launch pad makes it a great deal more difficult than it will be when we have two at Kennedy and one at the west coast.

KSC LAUNCH PADS

Senator GARN. I can testify that with only one launch pad, the launch does do a considerable amount of damage to the pad. When we were still back with 51E, a real problem was impinging on 51D, not because you couldn't have two flying up there at the same time or bringing them back and landing them on the runway at a different time, but you could not get the launch pad reconfigured and refurbished for that next launch.

When will the next launch pad be finished?

Mr. BEGGS. Vandenberg?

Senator GARN. I am speaking of the one at Kennedy.

Mr. BEGGS. We are aiming for January. We are a little ahead of that schedule right now, Mr. Chairman. So that one is coming along very, very well.

Senator GARN. I have at least 13 pages of detailed questioning on the shuttle market position, technical briefings, orbiter production capabilities, shuttle Centaur Upper Stage. I am not going to take the time of the committee to go through all of those detailed questions on the operations, but I will submit them to you and hope we can have a prompt response in writing to those questions for the subcommittee.

Mr. BEGGS. Yes, sir.

Senator GARN. Senator Proxmire?

IMPACT OF FREEZE

Senator PROXMIRE. I have just a few questions that can be answered rather quickly, Mr. Beggs.

Last week the Senate Budget Committee voted to freeze next year's NASA budget at the fiscal year 1985 level. That would result in a cut of $371.3 million in your 1986 request. Could you tell us where you would take that reduction?

Mr. BEGGS. We would have to look at entire programs. We would probably start with the advanced technology satellite. We would cut back on the commercialization activities. We would cut back in some of the aeronautics systems programs, such as the advanced turboprop. We would probably eliminate the orbital maneuvering vehicle starting this year. And beyond that, we might have to reach into the shuttle itself and cut back on the flight rate.

Senator PROXMIRE. Wouldn't it make sense to achieve the bulk of the cut by postponing space station expenditures for a year? After all, it is not an established program.

Mr. BEGGS. Well, sir, we don't think so. It wouldn't solve our problem totally. It would set us back very severely on a program that has some momentum behind it. If we are going to cut back, if we are going to stop the space station, I would argue we ought to complete the phase B efforts and take a look at it at that point. I would propose, if I am required to hold at the 1985 level, to continue that effort through phase B. The activities we have ongoing are not terribly expensive in terms of reaching a decision point on the overall development of the program.

OPERATING COST OF SHUTTLE/TRANSFER OF FUNCTIONS

Senator PROXMIRE. Can you tell us how much it will cost to operate the shuttle in 1985 and 1986 and what percentage of those operating costs will be paid for through user fees in those years?

Mr. BEGGS. $1.8 billion in 1985 and $2.1 billion in 1986. In the aggregate of those two, about 23 percent will be reimbursed, just slightly less than $1 billion.

Senator PROXMIRE. As you know, your former Deputy Administrator, Dr. Mark, apparently believes NASA should get entirely out of shuttle operations to leave the agency free for developmental programs, and that the first step is to transfer mission control for the space program to the Kennedy Space Center. How do you react to that suggestion?

Mr. BEGGS. Dr. Mark and I discussed that many times. Generally, in the long term, I agree with his assessment that we ought to move the center of gravity of the operation to Kennedy. We are starting to do that. That probably will never be a complete consolidation at Kennedy because we have many very expensive facilities in Houston which could not be transferred or could not be transferred except at very large expense. But, we will, and have started to move things out of Johnson over to Kennedy as the program matures.

Now we are also proceeding to consolidate a number of the activities at Kennedy. If you have watched the procurement activity we have had going on, we have consolidated the shuttle processing and we are consolidating the logistics activities and the maintenance activities. The purpose of all that is to make the entire shuttle system more autonomous, if you will. If the country decides to spin it off at some future date, it will be possible to do that relatively easily.

One final point, Senator Proxmire. We did commission a study on this, which will be coming to this committee very shortly, by Ed Smylie, one of our former Associate Administrators in NASA and now with RCA, to study just this point. Their conclusion was that in the near term, it is probably not possible to separate it from NASA, but that possibly in the long term it would be.

SPINOFF OF SHUTTLE OPERATIONS

Senator PROXMIRE. At what point, if ever, do you think the shuttle program will be primarily the responsibility of the private sector? Is it ever likely to be?

Mr. BEGGS. It is the responsibility of the private sector right now in the sense that we contract for about 90 percent of the activity that goes on. The private sector contractors are fully involved in preparing the shuttle for launch, in the logistics area, and in the area of mission operations. That is, they work to define the missions, create the profiles, and do all the other good things. That is private right now, and you could, if one wanted to, hire an overall integrating contractor to take over the entire thing.

The only problem with that is that the NASA facilities and the NASA personnel right now are very intimately involved in the flight operations themselves, and it will be a while before you can spin that off.

SMALLER SPACE SCIENCE MISSIONS

Senator PROXMIRE. Dr. Freeman Dyson, whom, as you know, is a highly respected scientist at the Institute for Advanced Study at Princeton, has charged that space science projects have become too large and inflexible. He claims that such projects take so long to complete that in most major missions the instruments were designed to answer questions that seemed important a decade or more earlier.

Dyson would prefer to see space science move in small steps, allowing each specialized mission to determine the questions the next project should answer.

Couldn't NASA get more bang for the buck by reallocating at least some of its dollars to smaller space science missions?

Mr. BEGGS. Yes, sir, we do and are. We have a number of ongoing activities. We took that criticism very seriously. It is true that if you go back in the seventies, we have promised scientists that they will be able to fly relatively small, inexpensive experiments on the shuttle and elsewhere, either free flyers or platforms and what have you, so they can bring their graduate students in and define an experiment, fly it relatively quickly, and at low cost. We are trying to expand that list all the time.

We do have ongoing a number of what we call spartan payloads, which is a simple way of integrating into the shuttle with experiments. This is a small program where we are inviting broad participation from the university community. We still operate our balloon program which allows a means to take experiments into the upper atmosphere. We have a large amount of aircraft research in the aeronautics program, which the university community takes part in, that allows them to do relatively small experimental and research work. We still have the sounding rocket program. We have a joint program with Germany called the Rosat which is running at $20 million or so a year, which is providing instruments on what will essentially be a joint satellite.

The list goes on and on. I point to one in which we take particular pride. As you know, we had three IC spacecraft which were in orbit and doing scientific work. We found a way of redirecting one of those spacecraft to take a close look at a comet, not the Halley's, but the next one coming around called Giacobini-Zinner. One of those spacecraft is now on its way to do an important piece of science and observing a comet at close range. We got that on the chief, if you will. We are trying to do that.

COOPERATIVE ACTIVITIES WITH U.S.S.R.

Senator PROXMIRE. Thank you, Mr. Beggs. That is an impressive answer.

I apologize to the chairman for prolonging this hearing. I have one other question I would like to ask.

Senator Matsunaga has introduced a resolution asking NASA to coordinate any plans to land a man on Mars with the Soviet Union. That seems to be a goal that both counties will undoubtedly pursue. The thought behind the resolution is if they pursue it jointly, it will save resources. Are there any plans to coordinate such an effort with the Soviets?

Mr. BEGGS. We have had some informal discussions with Mr. Zomdev, who is the head of their civil space program. I think if we were to mount a mission to Mars, it would not only be desirable, it would be essential that we did a collaborative program with the Soviets because it would probably take most of the resources that both we and they could get together in order to mount that mission. They seem to be interested in discussing collaboration of that sort again. I say again because they, as well as we, have not been very interested in getting together to discuss. But, Mr. Zomdev made a trip to this country earlier this year and apparently for the purpose of discussing some possible collaboration in the future.

I think we could well get interested in that. Our past problems that we have had in dealing with them, I guess, have dissipated somewhat now. I look forward to the possibility of some future collaboration.

Senator PROXMIRE. As far as I know, there would be no military implications in a trip to Mars anyway.

Mr. BEGGS. No, sir; I can't see it.

Senator PROXMIRE. Any kind of cooperation, it seems to me, would be constructive.

Mr. BEGGS. I think as well you could probably divide the job so that the technology we develop could be fenced off and the problem of technology transfer that a lot of folks worry about in this country could be adequately handled.

Senator PROXMIRE. Thank you, sir.

Thank you very much, Mr. Chairman.

Senator GARN. No military implications unless there are bald-headed green men on Mars, I guess. [Laughter.]

There are other questions. Senator Leahy had some additional questions for your response in writing. Some of the other members of the panel do as well. So we thank you for your willingness to testify. We will look forward to an additional hearing at some time in the future after Discovery flies. Thank you very much.

Mr. BEGGS. Thank you very much.

[CLERK'S NOTE: All of the questions for NASA follow the second part of the NASA hearing on the topic of Automation and Robotics.]

AUTOMATION AND ROBOTICS TECHNOLOGY

STATEMENT OF ROBERT FROSCH, VICE PRESIDENT, GENERAL MOTORS RESEARCH LABORATORIES, FORMER NASA ADMINISTRATOR

ACCOMPANIED BY AARON COHEN, DIRECTOR, RESEARCH AND ENGINEERING, JOHNSON SPACE CENTER

Senator GARN. We will continue the hearing. Please come forward, Dr. Frosch.

We will now have a discussion of NASA's plan to advance automation and robotics technology for the space station and the U.S. industrial base on Earth.

I am pleased to welcome Dr. Robert Frosch, vice president of General Motors Research Laboratories and former NASA Administrator, and Mr. Aaron Cohen, Director of Research and Engineering of the NASA Johnson Space Center.

Dr. Frosch served as chairman of the steering committee over a study performed by the California Space Institute addressing automation and robotics [A&R], which included a distinguished panel from industry and the academic community. The study has identified key A&R technologies required for the space station.

Mr. Cohen served as Chairman of the NASA Space Station Advanced Technology Advisory Committee, charged with identifying how NASA will implement the concepts of the contracted studies on automation and robotics.

As you know, this subcommittee is concerned with the issue of how NASA, through the space station program, will be on the forefront of the next industrial revolution in robotics, artificial sensing, and artifical intelligence.

The Senate ought to be able to help you on that last point. [Laughter.] There is a lot of that around this particular body, and on the House side as well.

This is a study that we discussed earlier. As you well know, the committee and the House committee last year felt that the mission was not well enough defined. We had not tried well enough to strike that balance between man tended and robotics. That is why the money was held up pending the completion of this study.

So I certainly want to first express my thanks to you gentlemen for your work in this area and all of those who participated in the study, and we look forward to your testimony.

AUTOMATION AND ROBOTICS PANEL

Dr. FROSCH. Thank you, Mr. Chairman. It is a pleasure to appear before you today to testify on the work of the automation and robotics panel. As you know, the panel was arranged by agreement between NASA and the Congress, this committee, as part of the activities supporting the establishment of NASA policy on automation and robotics.

The panel was established by the California Space Institute of the University of California under a NASA grant. Professor James Arnold, who is director of that institute, Dr. Charles Rosen of Machine Intelligence, Inc., and I acted as a steering committee for the panel. Dr. David Criswell of the California Space institute organized the panel and was senior technical advisor.

The panel brought together experts from industry, universities, national laboratories, other Government agencies, and NASA to perform an independent study of how NASA could use automation and robotics in the space station in ways that would be most useful to carrying out the mission and that would lead to useful benefits to the U.S. economy and industry on the ground.

The steering committee helped in guiding the choice and recruitment of panel members by providing its views to the panel. Professor Arnold and Dr. Rosen participated in the meetings of the panel, and we also consulted with each other and with Dr. Criswell throughout the work. We read and commented on various drafts of the report.

The panel did a tremendous amount of work in a relatively short time, covering the possible uses of automation and robotics in the station. In the discussions the panel specifically includes in automation and robotics those technologies called artificial intelligence or machine intelligence.

The panel considered how to design the station for the best use of all these emerging technological advances and how to assure a growth capability for use of these technologies in the station. It studied the technological adavncements that should be aimed at for the greatest benefits to the station and to terrestrial industry.

It also considered, drew conclusions, and made recommendations with regard to their views of the technology directions for which NASA should take lead responsibility, those on which NASA support should apply leverage, and those which NASA can exploit. It tried to plan for the deliberate advancement of these technologies in both their space and terrestrial applications.

Some specific funding estimates are made in the report. The panel also makes recommendations on the management requirements and structures that it feels are needed for success.

In the short time appropriate for this testimony I will not try to outline the contents of the panel report but will only make my own general comments on the report and its various aspects.

While the development of the detailed plans for, and building of, the space station and the future development of the technologies of automation and robotics will no doubt result in changes that adjust the appropriateness of many aspects and details of the report, I believe the recommendations are realistic and supportable, keeping in mind that they deal with the application of rapidly changing technologies from the next few years into the next 25 years and beyond.

The funding levels discussed are well scaled to the place of these technologies in the space station and to the scale of effort that will be necessary to create the station. They should be manageable within the scale of NASA budgets necessary to accommodate the station development. The organizational recommendations are based on sound principles and can be accommodated in a reasonable way within the NASA organization.

If the technical recommendations are followed, the infusion of NASA money, objectives, and interest into the development of automation and robotic technology should have an important effect in enriching the directions that technology takes and in pushing new ideas and possibilities required by the space station application.

These new directions, because they are in areas of considerable difficulty and complexity, will lead to new knowledge, new technology, and new application ideas which will make important contributions to the development of terrestrially useful and important applications of the whole field.

The effect may not be most important in specifically identifiable devices and gadgets but, rather, will be in new directions and ideas which will have important effects and payoff.

The program recommended will have good connections between the NASA Automation and Robotics Program, possible industrial contributors and users, and the academic community. These connections can ensure a continuous flow of benefits resulting from the work into industry from the beginning of the program. With the establishment of an interested community of contributors to and participants in the program, and interested potential users of results, many aspects of the transfer of the resulting technology into terrestrial use may be essentially automatic.

At the very beginning of the program NASA may be more a user and exploiter of the technology, but as the program matures, the agency will become a major participant and in many aspects of the technology can become a leader.

The work of the panel, even before its report is formally issued, has been important because it brought together a community of NASA and non-NASA participants to consider the problems of the applications of automation and robotics to the space station. This has stimulated the thinking of the members and has established the beginning of a community of interest between the NASA space station team and the automation and robotics community.

The NASA group has been working with and listening to the panel and has begun to build these ideas and recommendations into its thinking. The work is well begun, and the mandate of the Congress expressed in Public Law 98-371 of the 98th Congress is being carried out.

The use of automation and robotics in the planning of the space station has begun and will continue as the station is designed and built and throughout its continuing life. The desired effects of the stimulation of this important technological area will follow from this initiative.

Thank you, Mr. Chairman, for this opportunity to express my views to the committee. I will be happy to try to answer questions.

Senator GARN. Please go ahead.

STATUS OF ADVANCED TECHNOLOGY ADVISORY COMMITTEE REPORT

Mr. COHEN. Mr. Chairman, it is a pleasure to be here today to provide you a status of the Advanced Technology Advisory Committee's report on automation and robotics for the space station.

An important stimulus to focus the agency's attention on automation and robotics has been provided by Congress in its mandate to study the advancement of state of the art of automation and robotics for the space station and for the U.S. economy.

In order to provide this report, we broke it down in three subtasks. This report is to be provided by April 1, 1985. The subtasks were the Advanced Technology Advisory Committee's report which was made up of NASA people, NASA participants; the Automation and Robotics Panel Report, administered by Cal Space, made up of academia and Government people; and the aerospace contractors report.

In putting the Advanced Technology Advisory Committee's report together, it was an open and interpretive process and relied very heavily on the data supplied by the Automation and Robotics Panel and the aerospace contractors. A summary of some recommendations that are coming out of the Advanced Technology Advisory Committee's report are as follows.

Automation and robotics should be a significant element in the space station program. The initial space station should be designed to accommodate future evolution and growth in automation and robotics. The initial space station should utilize significant elements of automation and robotics technology. Criteria for the incorporation of automation and robotics technology should be developed and promulgated. Verification of the performance of automated and robotics systems should be stressed, including terrestrial and space demonstrations, to validate technology for space station use. Use should be made of technology developed for industry and government. The techniques of automation should be used to enhance NASA's management capability. NASA should provide measures and assessments to verify the inclusion of automation and robotics in the space station program.

For space activities, we believe the benefits of advanced machine intelligence robotics and automation will be increased productivity, increased responsiveness to innovation, lower cost of operations, and improved reliability, greater autonomy, the ability to perform tasks unsuited to humans alone, a reduced exposure of humans to hazardous situations. And there will also be benefits that accrue to the U.S. economy. The space station will be more suitable for commercial ventures, with flexible and reliable systems and optimum use of crew time.

The advantages of automation and robotics stimulated by space ventures can be applied in terrestrial situations, in settings ranging from the factory floor to the bottom of the sea, to the homebound elderly.

In putting our report together, we have the expectations that in the initial space station we will have much more automation and robotics than we have had in previous spacecraft. We foresee we will have expert systems controllers for electrical power, guidance and navigation control, communication and tracking, information management system, and an environmental control and life support. These controllers that will be enhanced by expert systems for trend analysis, fault diagnosis, statusing, and scheduling.

We also foresee the teleoperations with a dexterous end finger will be needed for various fabrication tasks. We also foresee the use of voice control systems.

Mr. Chairman, that concludes my statement.

Senator GARN. Thank you very much, gentlemen.

[The statement follows:]

STATEMENT OF AARON COHEN

Mr. Chairman and Members of the Subcommittee:

It is a pleasure to appear before you today to discuss the activities of NASA's Space Station Advanced Technology Advisory Committee. This testimony will briefly review Advanced Technology Advisory Committee (ATAC) activities over the last year in preparation of the report to Congress on the potential for advancing automation and robotics technology for the Space Station and for the U.S. economy.

BACKGROUND AND INTRODUCTORY REMARKS

In April 1984, at the request of the House and Senate Committees on Appropriations, NASA initiated a study to evaluate alternative Space Station systems design concepts and systems technologies which would use advanced automation and robotics. To accomplish this automation study, NASA contracted with the California Space Institute to oversee an independent, non-aerospace industry/university team. Additionally, four aerospace contractors (GE, Hughes, Martin Marietta and TRW) were tasked with automation and robotics conceptual design studies of representative functions on the space station and Boeing contributed a fifth case study. Finally, SRI International was engaged to perform certain technology evaluation and forecasting, in general and in support of the case studies.

As part of the Conference Report (House Report 98-867) accompanying the FY 1985 HUD-Independent Agencies Appropriations Act (P.L. 98-371), the Conferees noted that the Space Station program offers an opportunity to stimulate the development of advanced technologies in the fields of automation and robotics. To that end, P.L. 98-371, dated July 18, 1984, provides that:

> "...the Administrator shall establish an Advanced Technology Advisory Committee in conjunction with NASA's Space Station program and the Committee shall prepare a report by April 1, 1985, identifying specific space station systems which advance automation and robotics technologies, not in use in existing spacecraft, and that the development of such systems shall be estimated to cost no less than 10 per centum of the total Space Station costs."

In their report the Conferees further noted that NASA should examine existing systems "whose potential for enhancing automation and robotics technologies appears promising," and that it was their expectation that such technologies might not only "increase the efficiency of the station itself" but also "enhance the Nation's scientific and technical base leading to more productive industries here on Earth."

As a result of its examination, the Advanced Technology Advisory Committee agrees that a key element of the "right" technology for the Space Station era is extensive use of advanced, general purpose automation, robotics, and artificial intelligence. This could include many systems and devices (such as computer vision, expert systems, and dextrous manipulators) that have been made possible by recent advances in artificial intelligence, robotics, computer science, and microelectronics. However, the experts in this technology tell us that while many of these systems are or will be available for the initial Space Station, other technologies, which would provide general purpose infrastructure support functions, characterized by greater flexibility, adaptability, autonomy and intelligence, will require substantial research and development investment in order to reach maturity for use in evolutionary Space Station.

The Advanced Technology Advisory Committee (ATAC) was constituted in the fall of 1984, and has drawn upon the work of the Automation and Robotics Panel, led by the California Space Institute. The California Space Institute study is being submitted with the ATAC report to the Congress. As a result of our examination directed by the Congress and our review of the Cal Space Panel and contractor efforts, and an assessment of the engineering implications of the user and customer mission requirements, the ATAC has come to believe that a great deal of advanced automation and robotics may be needed on an evolving Space Station complex to provide the kind of flexible, adaptable, multi-purpose facilities in space which will be most productive and supportive of the users, customers, and operators. The Space Station (and the manned space program in general) would have used a significant amount of automation and robotics, so in one sense we are dealing with how much more advanced, general purpose automation and robotics may be used. A great deal has already been achieved to integrate advanced automation and robotics planning into not only the NASA activities, but also those of the Space Station Phase B contractors through the requirements stated in the Request for Proposals.

I believe the ATAC report (consisting of two volumes) can guide NASA in implementing this advanced technology to meet the needs of the Space Station users with highly productive and low operating cost facilities. This will be important to the commercialization of space as well.

Following my appointment by the NASA Administrator as Chairman of the ATAC, I selected a group of distinguished members, not only because of their professional experience and capabilities, but also because the organizations they represent will be responsible for assuring a high level of automation and robotics accommodation aboard the initial Space Station and its associated platforms which NASA undertakes as a result of the recommendations of both the Cal Space and ATAC studies. This gives the best opportunity to sustain the enthusiasm and guide the activities at the working level.

The membership of the Advanced Technology Advisory Committee is as follows:

Mr. Aaron Cohen, Chairman Director of Research and Engineering	Johnson Space Center
Mr. John H. Boeckel Director of Engineering Center	Goddard Space Flight
Mr. J. Larry Crawford Assistant to Chief Engineer	NASA Headquarters
Mr. Lynwood C. Dunseith Assistant to the Director of Space Operations	Johnson Space Center
Dr. J. Stuart Fordyce Director of Aerospace Technology	Lewis Research Center
Mr. Paul F. Holloway Deputy Director Center	Langley Research
Mr. James E. Kingsbury Director of Science and Engineering Center	Marshall Space Flight
Mr. Allen J. Louviere Manager of Level B Systems Engineering and Integration	Johnson Space Center
Dr. Robert R. Nunamaker Chief Engineer	Ames Research Center

Mrs. Donna L. Pivirotto
Manager, Space Station Office   Jet Propulsion
Laboratory

A key element of the approach taken by ATAC from the outset was to be aggressive in identifying the best the technology has to offer as input to the Space Station definition and preliminary design process, but not to subvert or overly constrain the process or the managers prior to this very detailed activity.

Another objective was to involve industry, academia, and aerospace contrators in identifying specific Space Station systems which advance automation and robotics technologies through cooperation with, and integration of, the various automation/robotics tasks: the aerospace contractor case studies; the Cal Space Automation and Robotics Panel effort; and the Advanced Technology Advisory Committee (ATAC) study. The organizational methodology used for NASA's Space Station automation studies is depicted in Figure A. The Manager of the automation study is Mr. Dan Herman, NASA Headquarters Office of Space Station, and the Deputy Manager is Dr. Victor Anselmo, NASA Headquarters. Dr. Robert A. Frosch, Vice President of General Motors, served as Chairman of the Steering Committee. The California Space Institute of the University of California formed the Automation and Robotics Panel which consisted of representatives of industry, academia, and government as listed here:

*Prof. J. R. Arnold, Cal Space
Prof. R. Cannon, Stanford U
Dr. R. Cliff, DARPA
Mr. A. Cohen, NASA/JSC
Mr. C. J. Cook, Bechtel, Inc.
Dr. D. R. Criswell, Cal Space
Dr. D. Evans, Los Alamos Nat'L Lab
Dr. H. Forsen, Bechtel Nat., Inc.
*Dr. R. A. Frosch,
   Gen. Mtrs. Res. Lab.
Dr. O. Garriott, NASA/JSC
Dr. D. Groce, Science Appl.
Dr. R. M. Hambright, SW Res. Inst.
Dr. H. Hudson, U of C at San Diego
Mr. D. G. Jelatis, Sargent Indust.
Prof. G. Konecci, U of TX
Prof. G. Kozmetski, U of TX
Dr. M. Knasel, SAI
Dr. P. B. Linhart, AT&T Bell Labs
Dr. Sanjay Mittal,
   Xerox PARC
Dr. J. Niehoff,
   Science Appl.
Dr. R. Perkins,
   LANL
Dr. M. Raibert,
   Carnegie
   Mellon U.
Mr. M. Reiss, U.S.
   Senate
*Dr. C.Rosen,
   Machine Intell.
Dr. C. Ruoff, JPL
Prof. J. Schwartz,
   NY Univ.
Dr. S. Starks,
   U of TX
   Arlington

Prof. M. Minsky, MIT & TM
Prof. I. Triffet, U of AZ
Prof. R. Volz, U of MI
Dr. B. West, La Jolla
Prof. T. Williams, Purdue
Dr. M. Wiskerchen, Stanford, U

*Member of the Steering Committee

The panel was divided into subpanels to prepare the various sections of the Cal Space report. The ATAC Committee has tried to listen very closely to this Panel's technical recommendations.

As part of the effort, several aerospace contractors studied automation and robotics in specific areas, as follows:

Boeing	Operator/System Interface
General Electric	Space Manufacturing Concepts
Hughes	Subsystems and Mission Ground Support
Martin-Marietta	Autonomous Systems and Assembly
TRW	Satellite Servicing

In addition, SRI International provided a technology assessment based on the contractors studies, their knowledge of technology, and the anticipated technology readiness.

Because of the very limited time available, the contractors were directed to identify "drivers," or factors, for advanced automation leading to the identification of representative systems or mission scenarios within their study area. They were asked to study the automation/robotics application for the evolutionary Space Station without cost or technology readiness constraints. It was not intended that the contractor studies address all aspects of automation and robotics applications to the Space Station program, but to address representative applications believed to be typical of those requiring advanced automation.

An ATAC Support Group was formed to assist these efforts, as listed here:

Dr. Jon D. Erickson, Chairman	Artificial Intelligence Office, Johnson Space Center

Dr. Victor Anselmo	NASA Headquarters
Mr. Jon B. Haussler	Space Station Office, Marshall Space Flight Center
Dr. Stephen J. Katzberg	Space Station Office, Langley Research Center
Mr. Louis E. Livingston	Space Station Program Office
Dr. Henry H. Lum	Information Sciences Office, Ames Ames Research Center

They functioned as members of the Space Station Automation Study Team, observers at the Automation and Robotics Panel meetings, and as major participants in the support to ATAC. The ATAC support group assimilated the inputs from various contributors into the two-volume ATAC report. The Johnson Space Center Artificial Intelligence Office provided the initial draft of the report and integrated comments and revisions for the final version. Another eighteen NASA and JPL employees provided draft material. This further broadened the base of involvement in the Agency at the working level.

In addition to membership on ATAC and the ATAC Support Group, the Level B Space Station Program Office was involved through periodic briefings and copies of draft documents. All prime bidders for NASA's Space Station Phase B systems definition contracts were also provided draft documents in a timely manner so they were aware of our thinking.

The entire process for the Space Station Automation Study was open and iterative. In addition to the three iterative loops displayed in Figure A, there were many information interchanges. All meetings, presentation documentations, etc., were completely open and available to all participants. All substantive outputs of this effort were made available in a timely manner to all interested parties. This total effort required and received extraordinary cooperation from all participants.

The objectives of the ATAC examination are several:

- o Identify potential advances in the state-of-the-art in automation and robotics technologies for use in the Space Station and to benefit the U.S. economy.

- Provide guidance for NASA Space Station program managers and prospective Space Station definition contractors to direct their efforts toward examination of the potential for advancing automation and robotics technologies though their incorporation in the overall development of the Space Station.

- Document, in a single convenient source, important considerations in automation and robotics, specifically:

  - --NASA Space Station engineering and programmatic aspects
  - --Recommendations of the academic and industrial community
  - --Descriptive and background material on the relevant technology
  - --Case studies of applicaions of advanced automation and robotics
  - --Technology projections and research recommendations

Documentation of the results, which are nearing completion, will be provided as follows:

- The Executive Overview, Volume I, which synopsizes the major findings of the study.

- The Technical Report, Volume II, which provides:

  - --Some general background to familiarize the reader with the technologies and potential of automation and robotics
  - --The Space Station design considerations of importance for automation and robotics
  - --The state of the technology and needed advances
  - --The guidance to be given to potential Space Station contractors so their efforts will result in a plan for advancing these technologies
  - --Considerations for technology transfer to U.S. industry and for space commercialization

- The companion document "Automation and Robotics for the National Space Program," by the Automation and Robotics Panel, led by the California Space Institute, which provides independent, corollary findings.

Related documentation of studies done by aerospace companies and by SRI International is referenced by SRI International is referenced and should be read in conjunction with the ATAC report.

PRELIMINARY RESULTS STILL UNDER REVIEW

For space activities, the ATAC believes the benefits of advanced machine intelligence, robotics, and automation could be:

- Increased productivity--with astronauts functioning as managers on behalf of station users rather than as operators carrying out routine functions.
- Increased responsiveness to innovation--with the automated Space Station being more flexible and adaptable.
- Lower cost of operations--with systems that can run at peak efficiency.
- Improved reliability--with improved detection, diagnosis, repair and recovery from abnormal situations.
- Greater autonomy--with improved monitoring and control of station systems and less reliance on ground support.
- The ability to perform tasks unsuited to humans alone--such as the assembly of large structures.
- A reduced exposure of humans to hazardous situations, such as extravehiculr activities, fueling tasks, and servicing satellites in very high (geosynchronous) orbits where radiation may be harmful.

Benefits could also accrue to the U.S. economy because:

- The Space Station would be more suitable for commercial ventures with flexible and reliable systems and crew time for management action.
- The advances in automation and robotics stimulated by space ventures could be applied in terrestrial situations in settings ranging from the factory floor, to the bottom of the sea, to the home-bound elderly.

The ATAC has identified guiding principles, which are intended to reflect the level and general areas to which advanced automation and robotics should be applied. Some are "baseline," in the sense that they should be followed loosely, independent of the actual level of funding made available for the Space Station effort. Others are meant to apply to an augmentation of the effort, should additional funds be made available along the lines indicated by the Automation and Robotics Panel. A summary of the preliminary "baseline" recommendations are as follows:

1. Automation and robotics (A & R) should be a significant element in the Space Station Program.
2. The Initial Space Station should be designed to accommodate future evolution and growth in A & R.
3. The Initial Space Station should utilize significant elements of A & R technology.
4. Criteria for the incorporation of A & R technology should be developed and promulgated.
5. Verification of the performance of automated and robotics systems should be stressed, including terrestrial and space demonstrations to validate technology for Space Station use.
6. Use should be made of technology developed for industry and Government.
7. The techniques of automation should be used to enhance NASA's management capability.
8. NASA should provide the measures and assessments to verify the inclusion of A & R in the Space Station Program.

Additional recommendations for an augmented effort are as follows:

9. The Initial Space Station should utilize as much automation and robotics technology as time and resources permit.

10. The evolutionary station should achieve, in stages, a very high level of advanced automation.

11. An aggressive program of long range technology advancement should be pursued recognizing areas NASA must lead, leverage, or exploit.

12. A vigorous program of technology transfer to U.S. industries and R & D communities should be pursued.

13. Satellites and their payloads accessible from the Space Station should be designed, as far as possible, to be serviced and repaired by robots.

NASA should use the Space Station "Definition and Preliminary Design" process (Phase B) to define the uses of automation and robotics to achieve increased human-machine productivity and the advances needed as the Space Station Program evolves. I understand that an implementation plan for assuring that Phase B will address automation and robotics needs adequately using a systems approach is being prepared by the Office of Space Station.

The potential for automation on the Space Station includes almost all systems and functions. There will be an evolutionary progression toward the goal of an autonomous Space Station. However, all initial designs should utilize as much mature automation as technologically feasible within cost constraints while not precluding eventual growth. Subsystems design should be targeted conceptually for the mature (year 2010) Space Station, and modifications should be made as necessary for the initial station, recognizing the readiness of the technology and the lead time required to achieve implementation.

Table A depicts some preliminary goals for advanced automation and robotics applications on the initial station.

TABLE A - IOC AUTOMATION & ROBOTICS APPLICATIONS GOALS

- ELECTRICAL POWER

  Controllers Enhanced by Expert Systems for
  --load distribution & switching
  --solar array orientation
  --trend analysis
  --fault diagnosis

- GUIDANCE, NAVIGATION & CONTROL

  Enhanced by Expert Systems for
  --station atitude control
  --experiment pointing
  --orbital maintenance & reboost
  --rendezvous navigation
  --fault diagnosis

- COMMUNICATION & TRACKING

  An Executive Enhanced by Expert Systems for
  --communication scheduling
  --rendezvous and docking
  --data rate selection
  --antenna pointing

- INFORMATION & DATA MANAGEMENT

  An Executive Enhanced by Expert
  Systems Control of
  --subsystem statusing
  --trend analysis
  --fault diagnosis expert system
  --redundancy & configuration management
  --data base management

- ENVIRONMENTAL CONTROL & LIFE SUPPORT

  Knowledge-based Controllers for
  --trend analysis
  --fault diagnosis
  --crew alarm
  --station atmosphere monitor & control
  --hypersonic chamber

- GENERAL

  Teleoperation of Mobile Remote Manipulator with collision avoidance

  Mobile multiple-arm robot with dextrous manipulators for EVA & IVA inspection/ORU exchange

  Systems designed to be serviced, maintained, and repaired by robots

  Primary Space Station control in space with appropriate backup

CONCLUSION

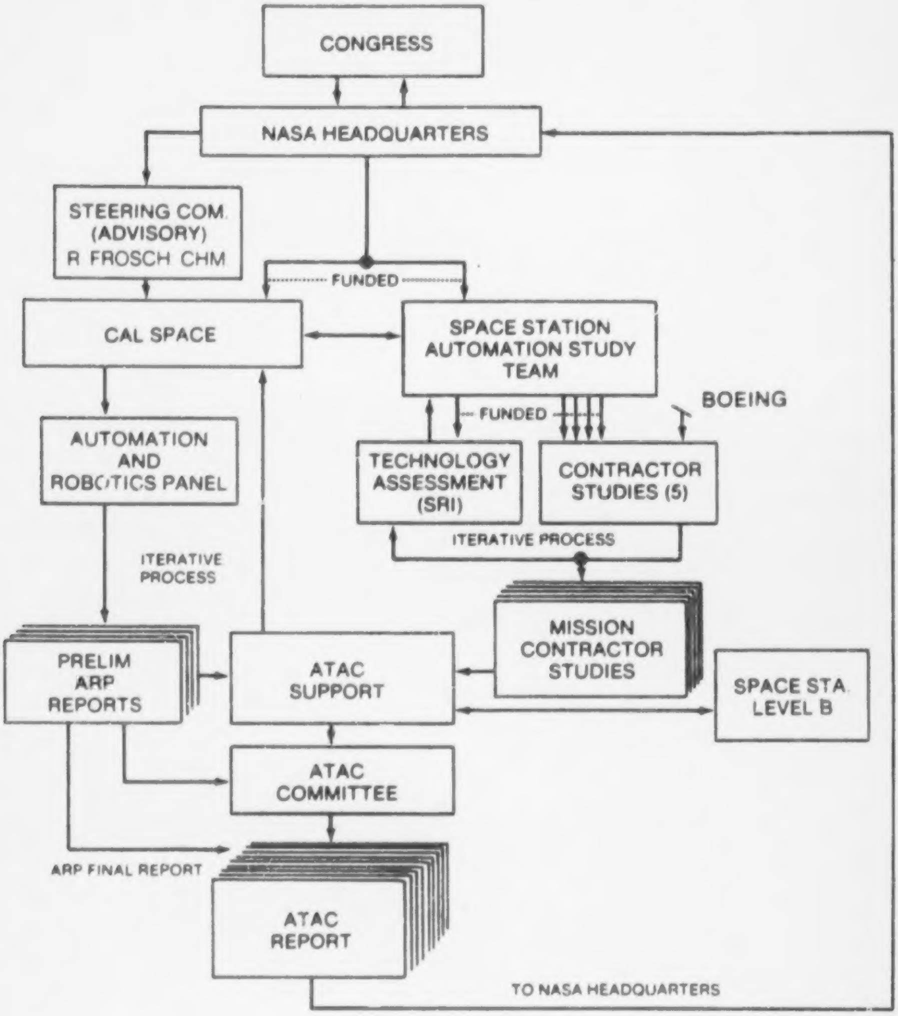
As you can see from the above activities, we are taking this subject quite seriously. ATAC feels an evolving Space Station could contain a high level of general-purpose automation and robotics. As a result of the Phase B activity, we will learn about the cost of the initial system, which could use this advanced automation and robotics, beyond what we would normally have employed.

We may find that using this advanced, general-purpose technology could increase initial costs, but significantly lower operating costs. However, those added funds might be wise investments to obtain a relatively large payoff when also taking account of potential for terrestrial applications. We are closely involved with the Space Station preliminary design process, so we will develop a good feel for uses, and systems and costs. Equally important, NASA should promote the transfer of the new technology to terrestrial situations where it will benefit the U.S. economy. These systems will provide the United States with important new methods of generating and exploiting space knowledge, and will thereby help preserve U.S. leadership in space.

We look forward to continuing to work with the Congress on advancing automation and robotics technologies.

Mr. Chairman, that concludes my prepared statement. I would be happy at this time to answer any questions that you or the Subcommittee might have.

Figure A.— Methodology for the Space Station automation study.


CONGRESS
NASA HEADQUARTERS
STEERING COM. (ADVISORY) R FROSCH CHM
FUNDED
CAL SPACE
SPACE STATION AUTOMATION STUDY TEAM
BOEING
FUNDED
AUTOMATION AND ROBOTICS PANEL
TECHNOLOGY ASSESSMENT (SRI)
CONTRACTOR STUDIES (5)
ITERATIVE PROCESS
ITERATIVE PROCESS
MISSION CONTRACTOR STUDIES
PRELIM ARP REPORTS
ATAC SUPPORT
SPACE STA. LEVEL B
ATAC COMMITTEE
ARP FINAL REPORT
ATAC REPORT
TO NASA HEADQUARTERS

STUDY RECOMMENDATIONS

Senator GARN. Dr. Frosch, do you feel the general recommendations of the Cal Space study are realistic?

Dr. FROSCH. Yes, I do, Mr. Chairman. I think they were carefully drawn to be realistic both in terms of where the technology is now and where it is likely to go and in the scale of work to be done.

There is not entire agreement in the community of automation and robotics and artificial intelligence people exactly as to the direction of future developments. But the way in which these recommendations are drawn, I think they can be followed out so that those things that become successful will be used in the space station and others can be dropped.

Senator GARN. Based on your familiarity with NASA, would you comment on the Cal Space funding and organizational recommendation?

Dr. FROSCH. The funding recommendations encompass both what the panel believes is a minimum level of program and what they believe is an appropriate level of program. The appropriate level, as I recall, is slightly more than the 10 percent that the congressional mandate suggested. The minimum would be somewhat less than that.

I think those funding levels fit very well with the kind of level of effort that goes with the space station.

The organizational suggestions are based on the principle that when you are trying to build a major engineering object on a schedule, and at the same time trying to develop new technology to go into it, you ought somewhat to decouple the development of the technology from the day-to-day urgent operations that are necessary to go into the building of the new design.

That is a sound organizational principle. It is one which I think the Administrator should be able to find a relatively straightforward way to incorporate in the NASA organization.

There is precedent in some of the ways in which aeronautical technology has been handled and some of the ways in which the development of technology for the present shuttle was handled.

BENEFITS BASED ON STUDY RECOMMENDATIONS

Senator GARN. If the recommendations are carried out, what types of benefits can industries on Earth anticipate and we would experience here on Earth? It is getting back to the spinoffs again. I realize this is far down the road. Asking a general question like that, I only expect a general answer.

Dr. FROSCH. My feeling from looking at the past history of spinoffs is the most important kind have been the kind in which the development of things in NASA became extremely influential in the directions of terrestrial technology. It is always very difficult to find specific objects and specific things, but the influence of the developments and directions of technology have been extremely important.

For example, when I came into the automobile industry, it became clear to me, even more than it had been before, that a very important spinoff from NASA was one which came quite a long while ago and which was embodied in a particular software program called NASTRAM. That is, it was a whole new way of going about doing the analysis of structural strength.

The availability of that program and that view of the subject has had a major influence on the development of all kinds of structural analyses in the aircraft industry, in the automobile industry, and I have seen it have some influence in architecture and in civil engineering.

Now, it is very difficult to track the details of how that particular spinoff had an effect because it has now been transformed. Everybody has built their own software and their own systems around it. It has vanished into a whole stream of structural analysis development. Yet, the seed came out of a NASA attempt to understand its own business best.

I think the influence of NASA automation and robotics in the space station is going to be because the space station will have somewhat different requirements than we do; for example, in an automobile factory. The NASA automation and robotics will try to solve a somewhat different set of problems. It will turn out automatically that some of those solved problems contain solutions that are applicable to problems that we have on the ground but that we would not have pursued those because the origin of the solution is entirely different than we would have thought appropriate.

So I think what we can see is an influence on the future path of robotics. For example, it may well be that the attempt to apply expert systems and artificial intelligence to the rather complex environmental problems of the space station will require a complexity of use that we would not require in an ordinary factory; and yet, when we look at what has been accomplished—I am trying to jump ahead and see what it would be like looking back—we will discover that whole new techniques were developed for that very difficult problem which makes some things we wanted to do on the ground but didn't know how to approach quite possible.

These become very difficult to track in an accounting and economic sense but terribly important in their influence on the whole national technology.

IMPORTANCE OF SPACE RESEARCH

Senator GARN. One of the frustrating things for years has been sometimes not being able to quantify what has come out of NASA engineering and research. You would be amazed at the number of times over the years I get asked the question why are we wasting money in space when we have such important needs here on Earth?

First of all, my response is we have never spent a dime in space. Every dime of the NASA budget is spent here on Earth, creating jobs and all sorts of things. But it is too bad we are not able to quantify it more because it is a question that bothers me. that somehow it is a waste to do these things, because there is such a lack of knowledge of what flows backward from that. There are a lot of products you can identify specifically that we use all the time.

What you say is very important to those who want to evaluate a NASA budget. Of course, I have been and especially now will be accused, regardless of the past record and how many times Jim Beggs has been upset with me over the last 3 or 4 years when I have stepped on his and NASA's toes, by some people who want to believe that I simply will give NASA anything they want. I expect to continue to hear that, despite that is not the factual situation.

But it is frustrating when you are dealing with a governmental program that has had such a marked influence in the terrestrial world and what we do that it isn't possible to quantity that more and track it so they can say, "Yes, we spent a dollar here and wasted a dollar there, but we got four dollars back for it over here in some other area.'

It almost makes you feel like sometimes you would like to stop the whole program and then say, "See what you are missing? Now you will find out. We cut it all out and we spent that money someplace else, and what did you get for it?"

But I understand and knew you wouldn't be able to give me a more specific answer.

Dr. FROSCH. Mr. Chairman, I think the influence NASA had in the course of the creation of the computer revolution which is, of course, not entirely due to NASA influence, but in which NASA played an important role, has probably, if we could only track it economically, which nobody knows how to do, paid a good share of the bills for NASA in terms of increased U.S. economic productivity. It was an important participant and a stimulator because of the NASA needs.

Senator GARN. I think if you would quantify it, you would find out that it paid more than some of the bills, maybe more than all of the bills.

Dr. FROSCH. Maybe more than all of the bills.

SPINOFFS FROM SPACE

Senator GARN. Maybe more than all the bills totally. But that is something that maybe we will develop a computer someday that can do that. [Laughter.]

Talking about the advances in computers, though, it is interesting that the spinoffs to the private sector have now exceeded what NASA has to operate with. I have learned enough in the last four months those four GPC's are not enough. That is why we carry Spock and other things on board with us.

So the technology NASA helped spawn has yet to flow back to NASA in terms of what the shuttle is going to need in the future in the way of computer capacity and capability.

How should NASA and Congress review the progress of the implementation of the Cal Space automation and robotics recommendations? Do you have any feelings on that?

Dr. FROSCH. I think that this can happen fairly automatically in the congressional program and budget review process, if Congress and this committee continues its interest, which I am sure it will, and its mandate to the Administrator to report on what is happening in the space station.

This has an important interface with the organizational recommendation since that recommendation suggests that there be an at least partially identifiable organization and budget for automation and robotics so that it would be relatively easy to track and that there be an organizational entity in the space station organization which has a specific responsibility for getting that technology transferred into the work of the space station. So that those would all be identifiable capabilities.

In addition, there is a recommendation which I think is a sound recommendation that NASA establish an outside technical review group which would advise it on these operations, and so that review group could usefully become part of NASA's system for keeping track of itself, which is I think a traditional NASA means of doing so.

NASA has always been a considerable user of outside advisory groups, exactly for that reason, that you get somebody who is not enmeshed in the day-to-day operations and they can sometimes see things with a different view and a clearer eye.

The reports of such a panel, however it is created, could be extremely useful to NASA, and I think also to the Congress, in knowing what the automation and robotics program for the space station really looks like.

DIFFERENCE IN ATAC AND CAL SPACE STUDIES

Senator GARN. That was going to be my next question, whether you thought there should be an outside peer review group.

Mr. Cohen, would you briefly point out some of the differences between the recommendations of the Cal Space study and the NASA Advanced Technology Advisory Committee [ATAC]?

Mr. COHEN. As to the technical differences, there are really no technical differences. The technical recommendations of the Advanced Technology Advisory Committee and the Cal Space report were really basically the same.

The two reports had slightly different emphasis. The Advanced Technology Advisory Committee's emphasis was looking at the specific areas of automation and robotics and how it would affect various elements of the space station, systems or subsystems, both for the IOC and evolutionary type space station.

The Cal Space report came up with recommendations, but they used the expertise they had gathered in academia and government to really define what was the technology that was needed to enable the advancement of robotics and came up with a type of time frame required and the cost estimates required. Those are the basic two differences. But as Dr. Frosch said, it did recommend requirements for an organizational restructuring.

Senator GARN. Your statement indicates that NASA should use the space station preliminary design phase B contracts to define the advances required in automation and robotics. What guidance will you provide to the phase B contractors on April 1 when you transmit to them the ATAC report and the Cal Space study?

Mr. COHEN. The Advanced Technology Advisory Committee's report is a reference document on the contract, so it will be a document that certainly will be transferred and is a reference document.

There is an implementation plan that is being generated by the level B program office which will define the studies in terms of schedule on inputs and outputs that the contractors need to perform based on recommendations from the Advanced Technology Advisory Committee's report. This will also be put into what we call the engineering master schedule, which is really the framework that the phase B contractors will be doing.

Senator GARN. How does your report provide guidance for implementation of the Cal Space study recommendations?

Mr. COHEN. The Cal Space report will also be submitted to the contractors. As I stated, basically the technical recommendations of the two reports are the same. So it essentially picks up the essence of the Cal Space report.

INITIAL COSTS VERSUS OPERATING COSTS

Senator GARN. You indicate in your statement that implementing these technologies could increase initial costs but significantly lower operating costs. Do you have any guesses on percentage changes in initial costs and operating costs?

Mr. COHEN. Let me put that in a little different perspective also. There is not only the cost issue; I think it is really the productivity issue. It is not only the cost versus the reduction in operating cost; it is also the productivity issue. If you have six to eight crewmen aboard the space station, you would certainly like those people to be spending most of their time doing commercial work for commercial activities or science activities and doing little statusing or failure diagnostics and allowing the expert systems to be doing that. So you also want to make the crew more productive in the work they would be doing.

To put all of this together, the phase B study really is going to come up with the understanding of what the technology is going to cost and what the implementation is going to cost in the space station. Once you define the operating cost, with or without it, you can do a cost-benefit study.

It would be very hard for me to try to give you a guess. I am not sure I could guess right now. We said in our report that we had made the initial cost versus the operating cost. We feel very strongly that will be the case. But that is really what the phase B study should provide, in our mind

Senator GARN. Gentlemen, thank you very much. I appreciate your being here today, but most of all we appreciate your work and time on the reports that you have both been involved in.

Dr. FROSCH. Thank you, Senator.

Senator GARN. One more thing that I would like to ask you to do. That is if you would provide for the record a description of how the NASA Advanced Technology Advisory Committee proposes to implement the Cal Space recommendations, in more detail than we have talked about; an indication of how NASA will review the progress of the implementation; the means by which NASA will report to the Congress on the progress of the implementation; an indication of the basis for the ATAC recommendations; a single document showing a comparison of each of the Cal Space and ATAC recommendations in specific topic areas with an explanation of the differences.

You don't need to remember that. We will give you a list of it.

Thank you very much.

Dr. FROSCH. Thank you.

SUBMITTED QUESTIONS AND STUDIES

[CLERK'S NOTE: The automation and robotics studies conducted by the California Space Institute of the University of California and the Advanced Technology Advisory Committee of the National Aeronautics and Space Administration are included in their entirety and are located after the responses to the written questions:]

Questions Submitted by Senator Garn

AUTOMATION AND ROBOTICS

Question 1: Please provide the following: Description of how the NASA Advanced Technology Advisory Committee proposes to implement the Cal Space recommendations.

Answer 1: The NASA ATAC report includes nearly all of the Cal Space Panel technical recommendations. The contracts for Phase B require the contractors to use the ATAC report in definition and preliminary design studies and a Space Station Program Office Phase B Implementation Plan for A&R spells out the various milestones to be met. The Engineering Master Schedule is the plan which defines the work to be performed during Phase B and A&R tasks and decision points are scheduled. In addition, the NASA and contractor advanced development program in A&R will be carried out as an integrated program. The focused technology and systems engineering efforts also include A&R. A generic A&R technology advancement program is being carried out by the Office of Aeronautics and Space Technology.

Question 2: An indication of how NASA will review the progress of the implementation.

Answer 2: Tracking progress on the implementation of the Automation and Robotics plan is a feature of our Definition and Preliminary Design phase management approach. The Phase B contractors are required to report periodically on their Automation and Robotics plans. Reports will be due to support the two Reference Update Reviews, the Interface Requirements Review (IRR) and the System Design Review (SDR). Two technical integration panels at Level B have been assigned responsibility to integrate these activities. Formal reviews with the Associate Administrator for Space Station at IRR and SDR will status these efforts.

Question 3: The means by which NASA will report to the Congress on the Progress of the implementation.

Answer 3: Our approach to implementing the automation tasks, described in the ATAC report, will be described in our FY 86 Operating Plan. We will keep the Congress advised of our progress against the Operating Plan by continued liaison with the Congressional Staff and we will report progress as part of our FY 87 Congressional hearings.

Question 4: An indication of the basis for the ATAC recommendations.

Answer 4: NASA initiated a study to evaluate alternative Space Station systems design concepts and systems technologies which would use advanced automation and robotics. To accomplish this automation study, NASA contracted with the California Space Institute to oversee an independent, non-aerospace industry/university team. Additionally, four aerospace contractors (GE, Hughes, Martin Marietta and TRW) were tasked with automation and robotics conceptual design studies of representative functions on the Space Station and Boeing contributed a fifth case study.

Finally, SRI International was engaged to perform certain technology evaluation and forecasting, in general and in support of the case studies. ATAC was constituted in the fall of 1984, and has drawn heavily upon the work of the Automation and Robotics Panel, led by the California Space Institute. As a result of our examination and our review of the Cal Space Panel and contractor efforts, an assessment of the engineering implications of the user and customer mission requirements, the ATAC has come to believe that a great deal of advanced automation and robotics may be needed on an evolving Space Station complex to provide the kind of flexible, adaptable, multi-purpose facilities in space which will be most productive and supportive of the users, customers, and operators.

Question 5: A single document showing a comparison of each of the Cal Space and ATAC recommendations in specific topic areas with an explanation of the differences.

Answer 5: See separate sheets.

SCOPE OF RECOMMENDATIONS

ATAC:

- o Recommends Guiding Principles for General Purpose
- o Automation and Robotics on the Space Station
  - Basic Program (within $8B)
  - of Augmented
- o Recommends Goals for Advanced Automation and Robotic Applications
  - Initial Station
  - Evolutionary Station
- o Recommends Technology Transfer Approach and Mechanisms for Terrestrial Applications
- o For an Implementation Mechanism Recommends a Phase B Approach and Schedules
  - To achieve preliminary designs including A&R
  - To define costs
  - To plan demonstrations of A&R

Cal Space Panel:

- o Recommends Guiding Principles for General Purpose
- o Automation and Robotics on the Space Station
  - Defines Advancing the Technology Base and its Costs
  - Management Approach for Technology Advancement
- o Recommends Goals for Advanced Automation and Robotic Applications
  - Initial Station
  - Evolutionary Station
- o Recommends Technology Transfer Approach and Mechanisms for Terrestrial Applications

SCOPE OF RECOMMENDATIONS (CONTINUED)

o As further implementation detail provides Space Station design considerations for Advanced Automation and Robotic Applications for Core Station, Platforms, OMV, Ground Facilities, and user payloads for design engineers and representative examples of conceptual designs of systems using advanced A&R.	o Provides Space General Design Considerations for Advanced Automation and Robotic Applications
o Did not address	o recommends separate budget for basic and applied research program in automation and robotics

For conciseness to aid in clarity of understanding this "Comparison of Recommendations" refers by number to Cal Space Report Section 1.3 Recommendations (starting on Page 4) and ATAC Report Vol. I Section on recommendations (starting on Page 5)

Cal Space Recommendations	Topic	ATAC Recommendations	Difference
1.	Mature Station	10. and mature station	ATAC specific goals
2. and Exhibit A	IOC Accommodate	2.	none
3.	C/D Contractor Selection	2. (Paragraph on page 6)	none
4.	Breakthroughs	11.	none
5. and Exhibit B	IOC Features	2, 3, and 9; also Vol. II	ATAC Specific IOC goals
6. and Exhibit C	Demonstrations	3, 5, and 9	ATAC indicated Phase B plan for Demo's
7.	Control	3. IOC Goals & 10	none
8. and Exhibits D&E funding	R&D	1, 11	ATAC did not study or recommend costs at this time
9. and Exhibit F Funding	Long Range Advances	11	ATAC did not study or recommend costs at this time
10.	Continuity	11	ATAC indirect
11.	Management Structures	p. 10	none
12.	Management Organization	none	ATAC took no position
13.	Non-NASA Advice	none	(SSP Implementation Plan recommends Advisory Panel)
14.	Involve	6	none
15.	Tech Transfer	12 & Vol. II	ATAC more detailed mechanisms
16.	Beyond SS	1 & 7	none
17.	New Participants	11	none
-	Criteria	4	Major ATAC, not Cal Space
-	Measures	8	Major ATAC, not Cal Space
-	Satellites	13	Major ATAC, not Cal Space

Budget

Question: Would you briefly describe the major impacts upon the NASA FY 1986 budget, if the Agency were limited to its FY 1985 appropriation level?

Answer: NASA's FY 1986 budget request is nearly level with the FY 1985 after providing for inflation.

A freeze at the FY 1985 level would reduce the NASA request by about $400 million from the FY 1986 request. A reduction in funding of this magnitude after the absorption of the additional requirements would require a major restructuring of the entire NASA budget. The newest projects with the least investments, such as the OMV, ACTS, ATP, and Commercial Use of Space would probably be delayed or deferred. Finally, a reduction of this magnitude would have a ripple effect throughout the NASA organization through the breakup of research teams, changes in detailed project schedules and deferral of testing and integration activities which, when combined with the effects listed above, make it a certainty that a budget freeze at the FY 1985 level would have a major adverse impact on NASA.

Private Sector Services

Question: How much money did NASA receive for services provided to the private sector in FY 1984? How much is estimated for FY 1985 and FY 1986? Could you please provide, for the record, a detail of these amounts by services rendered?

Answer: The following chart provides actual 1984 money received from the private sector for services provided by NASA as well as estimates for 1985 and 1986.

	FY 1984	FY 1985	FY 1986
Launch and Landing Activities	312,334	266,136	317,480
Applications	3,662	4,348	3,200
Other	3,320	748	625
TOTAL	319,316	271,232	321,305

SES Bonuses

Question: How much have you included in your Budget Request for SES bonuses during FY 1986?

Answer: The FY 1986 Budget contains $1.1 million for SES Bonuses and Presidential Rank awards.

Five Percent Pay Cut

Question: NASA activities are heavily dependent of the personnel hired by contractors. These non-federal employees often work side-by-side with NASA employees and are virtually indistinguishable from their federal colleagues. One clear distinction, however, will be the proposed pay reduction of five percent for Federal employees. Are you anticipating any special morale problems with your work force because of this unique relationship with non-federal workers? What will failure to enact the five percent pay reduction have on your budget?

Answer: Even though contractor employees working at NASA centers are managed in an "arms-length" manner, enough contact exists so that we expect some morale problems if the civil service work force receives a five percent pay cut, while the contractor work force pay remains level or increases. We expect that the morale problem will, most likely, manifest itself in higher turnover, especially an increased retirement rate. We anticipate, however, that our civil service work force will continue to work to the high standards for which it has become known.

Cooperation with National Science Foundation on Supercomputers

Question: What is the current status of the Supercomputers? Would you be willing to repeat this cooperative effort at the time of the expiration of your next supercomputer lease?

Answer: NSF has sent teams to LeRC for site visits and to discuss the pending transfer. The LeRC Cray 1S supercomputer will be shipped upon installation, at LeRC, of the replacement Cray X-MP system. Cray anticipates a replacement system will be available in the fall of 1985. Procurement activities are on schedule.

Yes, based on three conditions. First, there would have to be a more powerful system available. The next generation of Supercomputers is anticipated in the 1986-1987 time frame. Second, the user's requirements would have to be greater than the current systems capability, necessitating the upgrade. Third, funding support would have to be made available. Given these three conditions this could prove to be a very satisfactory arrangement which NASA is eager to pursue.

Construction of Facilities

Question: In FY 1986, you are requesting $149.3 million for your Construction of Facilities program. This represents a decrease of $700,000 from the FY 1985 appropriated level.

Please provide, for the record, a listing of the specific projects included in your FY 1986 budget request, including the original request to OMB for each of these projects and the amount included in the budget.

Answer: The requested listing follows:

	($ in Millions)		
Project Title	To OMB	Budget Amount	Loc.
KSC Construction of Orbiter Modification and Refurbishment Facility	13.0	14.0	
KSC Construction of Thermal Protection System Facility	3.6	3.6	
KSC Modifications to Pad A Payload Change-out Room	2.2	2.2	
KSC Construction of Payload Control Rooms	1.2	1.2	
JSC Modifications for Enhanced Life Support Systems Testing	1.1	1.1	
MSFC Modifications for Advanced Technology Engine Test Stand S-IC	6.5	6.5	
NSTL Modifications for Space Shuttle Main Engine Support Systems	2.5	2.5	
GSFC Construction of Additions to Research Laboratory	3.8	3.8	
JPL Construction of Microdevices Laboratory	8.9	8.9	
ARC Construction of Numerical Aerodynamic Simulation Facility	8.2	8.2	
LaRC Modifications to 16-Foot Transonic Tunnel for Improved Productivity and Research Capability	4.9	4.9	
LeRC Modification of the Altitude Wind Tunnel	20.0	---	
VAR Modification of 64-Meter Antenna DSS-14, Goldstone, California	8.5	8.5	
VAR Modifications of 64-Meter Antenna DSS-45, Canberra, Australia	8.9	8.9	
VAR Repair of Facilities at Various Locations	22.0	22.0	
VAR Rehabilitation and Modification of Facilities at Various Locations	27.0	27.0	

VAR	Minor Construction of New Facilities and Additions to Existing Facilities at Various Locations	6.0	6.0
VAR	Facility Planning and Design	12.0	12.0
	TOTAL	168.3	149.3

Question: Please prepare a listing showing each of the items not included in the FY 1986 request that were, however, included in your original submission to OMB, include the amounts you requested for each of these items.

Answer: The requested listing follows:

	Project Title	($ in Millions) Requested Amount	Loc.
LeRC	Modifications of the Altitude Wind Tunnel	20.0	

Question: Please provide a list of those CofF projects that are related to shuttle operations, include the original request to OMB and the amount contained in your FY 1986 budget.

Answer: The requested listing follows:

	Project Title	To OMB	Budget Amount	Loc.
KSC	Construction of Orbiter Modification and Refurbishment Facility	13.0	14.0	
KSC	Construction of Thermal Protection System Facility	3.6	3.6	
KSC	Modifications to Pad A Payload Change-Out Room	2.2	2.2	
JSC	Modifications for Enhanced Life Support Systems Testing	1.1	1.1	
MSFC	Modifications for Advanced Technology Engine Test Stand S-IC	6.5	6.5	
NSTL	Modifications to Space Shuttle Main Engine Support Systems	2.5	2.5	

Question: Please indicate those items in the above list that are relating to maintaining or increasing the flight rate of the shuttle.

Answer: All items in the above list are related to maintaining the flight rate of the Shuttle except the JSC and MSFC projects. The Modifications for Enhanced Life Support Systems Testing at JSC is required for more efficient testing of advanced life support systems for spacecraft. The Modifications for Advanced Technology Engine Test Stand S-IC at MSFC is required for "hot firing" demonstration test of advanced propulsion systems for designing improved Space Shuttle engines.

Space Station - New Starts

Question: FY 1986 will be a year where you are moving forward quite vigorously in the area of space sciences. Your funding is up about 15 percent and several launches are expected including the Hubble Space Telescope, the Ultraviolet Telescopes, the Galileo Mission to Jupiter and the Ulysses Solar Mission. It also includes the Voyager encounter with Planet Neptune. There are also a number of areas where funding was not provided for FY 1986. These include several candidate projects such as the next phase of Gravity Probe-B a test of general theory of relativity, the Advanced X-Ray Astronomy Facility known as "AXAF," the Comet Rendezvous and Asteroid Flyby, the Ocean Topography Experiment Program or "TOPEX" as it is called and the "ISTP" or International Solar Terrestrial Physics Program. Which of these programs were included in your budget proposal to OMB? What is the current status of these candidate initiatives and when might development efforts begin?

Answer: The FY 1986 OMB budget proposal included TOPEX and a GP-B Shuttle Flight Engineering Demonstration as possible new starts. As a result of the overall federal budget constraints, and other considerations, these proposals were not carried forth as Agency new starts in the President's FY 1986 budget.

These two missions, as well as AXAF, ISTP, and CRAF are all currently under study, and advanced technology development is underway to ensure our readiness to perform the missions should budget conditions permit.

During the formulation of the FY 1987 budget, all of these missions will be rigorously reviewed. We will consider the input from our various advisory committees, the science community, and our internal science managers in the formulation of our budget, and the establishment of our FY 1987 priorities.

We are hopeful that all of these missions can be initiated over the next several years. The pace of new starts will depend on factors such as the U.S. economy, federal fiscal policies, etc.

Science, Applications and Planetary Launches

Question: Please prepare, for the record, a list of your candidate science, applications and planetary flight projects by fiscal year from FY 1985 through FY 1994.

Answer: This is a listing of the approved starts for FY 1985 and the candidate new starts for FY 1987 through the early 1990's.

FY 1985

Mars Observer
Scatterometer
Upper Atmosphere Research Satellite (UARS)

FY 1987

Advanced X-Ray Astrophysics Facility (AXAF)
Comet Rendezvous Axsteroid Flyby (CRAF)
International Solar Terrestrial Physics (ISTP)
Ocean Topography Experiment (TOPEX)
Gravity Probe-B Shuttle Flight Engineering Demonstration

FY 1988 and Subsequent

Geopotential Research Mission (GRMO)
Lunar Geochemical Orbiter (LGO) *
Space Infrared Telescope
Gravity Probe-B Science Mission (follow-on to engineering demonstration)
Earth Observing System (EOS) **
Geostationary Platform **
Saturn Orbiter/Titan Probe (SOTP)

* Planetary Observer
** Space Station Payload

X-Ray Astronomy

Question: The U.S. pioneered x-ray astronomy for space in 1962. The second High Energy Astronomy Observatory was operated from 1978 to 1981. The German Research Satellite (ROSAT) is scheduled to be launched by the Shuttle in 1987 and should provide major advances in X-ray astronomy. What is the relationship between ROSAT and the Advanced X-Ray Astrophysics Facility (AXAF)?

Answer: These two missions are highly complementary in nature, offering a clear contrast in primary scientific goals and capabilities.

The ROSAT mission will provide an extension of HEAO-2-class observations from about 15 percent of the sky to a uniform full-sky survey. It will be limited in several key areas with respect to AXAF, including energy range, spatial resolution, spectral resolutions, and sensitivity. The AXAF objective of mapping the x-ray emission from cosmic sources on unpredentedly small scales will be attained with its high spatial resolution (0.5 arc sec), which is approximately 10 times better than that attainable with ROSAT. The AXAF spectral resolution will allow the first detailed measurements of narrow x-ray lines in cosmic sources. ROSAT's primary thrust will be in its full-sky coverage, which should result in the detection of a large number of new sources. AXAF should benefit from the ROSAT survey which may identify many source regions warranting further, more detailed observation with AXAF.

Question: The glass procurement schedule for the Advanced X-Ray Astrophysics Facility (AXAF) is a key program long lead item. When can NASA be expected to make a decision to place a reservation for the production of Schott glass.

Answer: As noted, the procurement schedule for the mirror blanks is a long-lead item for AXAF. The current schedule calls for issuing an RFP for the mirror blanks in 1986 in preparation for a future new start. At this point and time a decision has not been made as to the source for the glass.

Question: Is AXAF currently scheduled for Phase C/D activities in 1987?

Answer: AXAF is one of several possible FY 1987 candidate new starts.

Gamma Ray Observatory

Question: The funding on the Gamma Ray Observatory (GRO) went up 36 percent in FY 1985 compared to the prior year. FY 1986, however, represents a 26 percent decrease from FY 1985.

What was your request to the OMB for this program for FY 1986?

What is the reason for the total project cost to be estimated at almost twice the original cost?

Answer: The GRO FY 1986 funding requirement submitted to OMB is the same as in the FY 1986 budget submitted to Congress.

The GRO project was approved as a FY 1981 new start with a planned launch in late 1985, and an estimated runout cost of $210-$270 million. However, the project was delayed in start-up activities due to Continuing Resolution restruction and impacted by two subsequent launch delays due to the FY 1982 amended Budget and the President's economic recovery program in FY 1983. Therefore, the increase over the original estimate was due primarily to inefficiencies caused by the schedule stretch out, the addition of retrieval capability, and some increase in the contractor's estimate for development of the spacecraft.

Question: Obviously the funding levels for the various programs in space science and applications are interactive and might be one reason for the seesaw effect in a particular program. Does the reduction in the budget request for FY 1986 indicate that the funding for the GRO will be diminishing between FY 1985 and the launch in FY 1988?

Answer: The funding profile for the GRO peaks in FY 1985. The future years funding for GRO will decline, but the decline does not indicate a seesaw effect on the GRO program. The decline is the orderly completion of work on the development project.

TOPEX

Question: With the NASA Launch of Seasat in 1978, it was demonstrated that remote sensing from space could be used to measure the topography of the oceans surface. TOPEX will provide information necessary to the understanding of ocean circulation. In exchange for the sharing of scientific data, the French have agreed to participate in the program and launch the satellite on Ariane, which should minimize program costs. What is the impact on not initiating TOPEX development in FY 1986? What is the level of activity planned for TOPEX in FY 1986?

Answer: The French continue to indicate their preference for flying their POSEIDON instrumentation on SPOT-3 until at least January 1986. The only impact that we can identify against not initiating the TOPEX mission in FY 1986 is that there may be less overlap in time with the complementary ERS-1 satellite mission and the potential international scientific programs, WOCE and TOGA. However, no serious impact to the scientific return is predicted.

Definition activities will be continued on the TOPEX mission in FY 1986 at the $4-6 million funding level.

Gravity Probe-B

Question: NASA has been supporting basic science research to test Einstein's General Relativity Theory for almost a decade at a fairly low level of effort. This effort referred to as Gravity Probe B (GP-B) has been increasing in size as elements of the prototype hardware are developed. The program has received praise from several Nobel Laureates, National Academy of Science Committees, NASA Review Committees and Jay Keyworth, the Science Advisor to the President. Would you please briefly describe where we are in this program?

Answer: The Gravity Probe-B mission, which is being pursued in two phases, will test Einstein's Theory of General Relativity by measuring the precession of gyroscopes in space with extreme accuracy. A Shuttle Flight Engineering Demonstration will be used to integrate and test critical technologies and provide key quantitative test results, both on the ground and in space, for a future free-flyer mission. GP-B is now in the advanced technology development phase, and will be considered as a FY 1987 new start candidate.

Sub-Orbital Observations

Question: Please provide, for the record, a list of the specific activities that are expected to be undertaken in FY 1985 and those that are expected to be undertaken in FY 1986 in your Sub-orbital Observations Program. Please indicate which activities will be conducted through balloons, which on sounding rockets, and which on high flying aircraft.

Answer: The FY 1985 and FY 1986 planned sub-orbital program activities are as follows:

NASA Sounding Rocket Program Activities

	FY 1985 Missions	FY 1986 Missions
Plasma Physics	23	27
Galactic Astronomy	5	2
Upper Atmospheric Research	6	6
High Energy Astrophysics	3	2
Solar Physics	5	3
Planetary Atmosphysics	3	4
Total	45	44

In 1985, the NASA and USAF are jointly conducting a sounding rocket campaign in Sandre Stromfjord, Greenland, comprised of seven NASA rockets and two Air Force rockets. Other launch sites which will be utilized in 1985 are: Wallops Island, White Sands, Fairbanks and Fort Churchill, Canada.

In 1986, the sounding rockets will be from Kirana, Sweden and Andoya, Norway.

NASA Spartan Program Activities

The Spartan program involves the combining of sounding rocket and orbiting investigation technologies. The Spartan program will allow low cost science experiment payload opportunities from the Shuttle. During FY 1985 completion of the Spartan carrier vehicle will be completed leading to the first launch of a Spartan payload on a Shuttle mission.

NASA Balloon Program Activities

Disciplines	FY 1985 Missions	FY 1986 Missions
High Energy Astrophysics	14	15
Galactic Astronomy	7	7
Solar/Plasma Physics	3	2
Upper Atmospheric Research	32	31
Test Flights	6	7
Reimbursable	5	5
TOTAL	67	67

Airborne Science and Applications Program Activities

FY 1985, the Airborne Science and Applications program will conduct investigations in infrared astronomy, Land Processes, Geology, Trospheric Chemistry, Atmospheric Dynamics, Plasma Physics, Ocean Processes, Planetary Science and Upper Atmospheric Research. Approximately 65-70 flights are planned in FY 1985 and FY 1986.

Space Telescope

Question: The Hubble Space Telescope development funding request for $127.8 million and launch date of mid-FY 1986 seem to indicate that the major program problems are behind us. How realistic is the total project development cost estimate of $1,175,000,000 to project completion? Would you give us a brief overview on what are major remaining milestones? Have there been any schedule slippages? What is the possibility of damage to the OfA mission during the vibration test of the entire telescope?

Answer: The Hubble Space Telescope development program is still on schedule and budget for a second half 1986 launch. The $1,175 million runout cost is tight and a challenge but, we feel, achievable. The program is now in the Assembly and Verification (A&V) stage of the development cycle in which all subsystems, including the scientific instruments, are brought together and assembled prior to starting overall system checkout and testing. Many difficult tasks remain to be completed before launch readiness. The major remaining items include delivery of the flight Fine Guidance Sensors, qualification testing of the remaining electronic modules of the Support Systems Module, functional and environmental testing of the completed observatory, and completion of the development and checkout of the many ground software systems.

The Fine Guidance Sensor development activities and the overall integration and testing of the Space Telescope system are somewhat behind schedule, but the overall system is coming together.

Vibration testing of the subsystems has been completed, and there is no planned vibration test of the entire Hubble Space Telescope.

Remote Sensing Technology

Question: Concern has been expressed that the United States is losing its technological lead in remote sensing. Since development and deployment of the Thematic Mapper, and transfer of operation of the Landsat system to NOAA, development of next generation technologies like the Multispectral Linear Array has slowed. Why has NASA cut back on the MLA development?

Answer: NASA discontinued only the development and demonstration flight of a cryogen cooled instrument; MLA technology development activities are being continued.

The technology being used in the MLA instrument development was being overtaken by the capabilities of other remote sensing instrument such as the solid state planar array technology of the Imaging Spectrometer which NASA has also been pursuing. The MLA represents a technology that was originally intended to provide a transition between the Thematic Mapper and the next generation Landsat technology. As a result of the recent technological progress in sincere, together with revised projections of flight opportunities, it now appears appropriate to by-pass the MLA instrument development and concentrate our efforts on the Shuttle Imaging Spectrometer (SISEX) as the next major technology development in remote sensing.

Tech Briefs

Question: Last year, NASA signed an agreement with a private publisher to turn over the cost of printing and distribution of NASA Tech Briefs. I support this cost saving initiative which also holds the promise of substantially expanding the dissemination of information on NASA-developed new technology. I understand that some concern has been raised over the "privatizing" of this publication. Have those issues been resolved?

Answer: The Joint Committee on Printing continues to express opposition to the decision of NASA to convert NASA Tech Briefs to a private sector publications. On February 20, 1985, the Administrator met with Senator Mathias, Vice Chairman, JCP; at this meeting it was decided that NASA would explore the possibility of transferring the responsibility of printing and dissemination of NASA Tech Briefs to the Government Printing Office (GPO). The circumstances for such a transfer are now under review by NASA and GPO. The JCP agrees that the current private publishing arrangements for NASA Tech Briefs shall continue until the matter is resolved.

The first volume of NASA Tech Briefs published by the private printer was issued this spring on time; distribution has already exceeded the previous OMB cap of 75,000 by some 12,000 copies without any marketing by the publisher whatsoever.

Question: While I support increasing NASA efforts to disseminate space program derived technology, I am puzzled why funding for this activity (RD 11-1) does not appear to drop as a result of the Tech Briefs transfer. Please identify the amount of cost savings involved in this transfer, amount of cost savings involved in this transfer by sub-account and explain why no reductions are displayed in your justification.

Answer: As the Tech Briefs issue is still under review, comments on the funding aspect would be premature. However, we will keep the Committee informed of the outcome.

Joint Endeavor Agreements

Question: I strongly support NASA programs to encourage the development of new industrial processes and services in space. A cornerstone of this effort is the use of Joint Endeavor's Agreements (JEA's) where typically NASA will provide access to space at reduced cost or for free to permit companies to expressment and develop new space technologies and processes. I will soon have the opportunity to directly, observe the activities of one such JEA--the Electrophoresis work of McDonnell Douglas and Johnson and Johnson. Some concern has been raised, however, as to the degree that NASA is committing itself to costly future year activities through these JEAs. Generally, how does NASA account for the potential budgetary implication of the JEAs? Please provide, for the record, a list of existing JEAs with a short description of each.

Answer: NASA is sensitive to the costs associated with entering into, extending, or modifying Joint Endeavor Agreements. Budgetary implications of JEA's are based on the number of flights NASA commits to in the JEA, as well as other support activity. The recently established Office of Commercial Programs has the responsibility to acquire JEA cost information for evaluation and use by the entire agency.

Listing of Existing Joint Endeavor Agreements:

1. Martin-Marietta Corporation

ACTIVITY: Development and demonstrate a propellant management device to obtain and evaluate fluid dynamics associated with the filling and expulsion of capillary propellant tanks under varying condition in a low-g environment.

2. 3M Corporation

ACTIVITY: To produce scientifically valuable space-produced organic crystals and thin films.

3. Spaceco Limited

ACTIVITY: Develop and demonstrate, using a shuttle environment monitoring system, the measurement of space shuttle cargo bay environment under launch, flight, and landing conditions. Experiment will ascertain the applicability of this technology to the monitoring of Space Shuttle environments on any mission where customers may require environment histories of the mission.

4. Fairchild Industries Incorporated

ACTIVITY: Design and develop a Shuttle-tended, mobile, unmanned space platform supported by ground-based systems and services. The space segment will be a spacecraft providing a platform in low earth orbit for scientific, commercial, and government users on a leased or service-contract basis.

5. Microgravity Research Associates

ACTIVITY: Develop and demonstrate the technology of electroepitaxy crystal growth on gallium arsenide or other crystals for use in the low gravity environment of space and ascertain the applicability of these technologies to the production of marketable crystals.

6. McDonnell Douglas Astronautics Company

ACTIVITY: Develop and demonstrate the technology of Continuous Flow Electrophoresis (CFE) in the low gravity environment of space.

Space Commercialization

Question: Could you briefly bring us up-to-date on the roles of the various agencies (DOD, DOT, NASA, NOAA, etc.) in space commercialization?

Answer: NASA's role in the commercial use of space is grounded in the agency's research and development mission. Over the past twenty-six years, NASA has worked closely with the aerospace industry to assure our nation's preeminence in aeronautics and space technology.

Congress recently amended the NASA Space Act of 1958 directing NASA to "seek and encourage, to the maximum extent possible, the fullest commercial use of space." NASA is moving expeditiously to involve the private sector, particularly non-aerospace companies, in the exploitation of space and its resources through the effective utilization of available tools, e.g., the Space Shuttle and eventual Space Station capabilities.

As expending the level of private sector investment in civil space and space-related activities is an objective of National Space Policy, the Department of Defense has had a limited role in encouraging the commercial use of space. In seeking an assured launch capability, however, DOD stated that the complementary expendable launch vehicle backup to the National Space Transportation System may have commercial potential.

The Department of Transportation has been designated as the lead agency for encouraging commercial expendable launch vehicle activities. The recently enacted "Commercial Space Launch Act" directs DOT to establish a regulatory framework for controlling commercial launch activities based on public health and safety and national security requirements.

The National Oceanic and Atmospheric Administration is the Department of Commerce focus for commercial involvement in remote sensing activities. NOAA is the lead government agency for the privatization of U.S. government Land Remote Sensing (LANDSAT) system.

Question: What interagency mechanisms have been established and what are their specific purposes?

Answer: Two interagency mechanisms have been established to coordinate the U.S. Government's efforts to encourage the commercial use of space. A working group formed under the auspices of the former Cabinet Council on Commerce and Trade has been an interagency forum for matters pertaining to the commercial use of space. A Department of Commerce official is Chairman of this working group, with a NASA official serving as Vice-Chairman. The status of this group under the new economic policy council has not been resolved. The Senior Interagency Group (Space) is an interagency forum for reviewing and advising on proposed changes to national space policy and for implementing policy for the overall U.S. space program.

Shuttle Pricing

Question: An issue which must be addressed this Spring is the Shuttle pricing policy. There have already been a number of hearings on this issue as well as several studies. The complexity of the arguments and technical disputes only clouds what I believe are fundamental policy issues. The basic issue is whether a domestic commercial launch industry is a viable notion. Mr. Beggs, given the limited number of anticipated communication for such launch services, is it your view that a domestic company has much of a chance in putting together a viable ongoing operation?

Answer: No matter the price for Shuttle flights in the future, we are confident that Ariane will continue to offer services priced at least somewhat below those of the Shuttle and probably domestic ELVs. Ariane's launch aggressive sales policies will probably provide them a competitive edge over the U.S. commercial ELV operators.

A commercial expendable launch vehicle industry appears likely to exist in the speciality markets being pursued by companies such as Space Services Incorporated and Orbital Sciences Incorporated.

Question: It has been suggested that NASA essentially priced itself out of the market for commercial launches by more than doubling current prices. What impact on the Shuttle flight rate do you believe will result from adoption of such a policy? What implications will this have on your commercialization effort and on the cost of the remaining shuttle operations?

Answer: Any reduction in Shuttle flight rate will result in a higher cost per flight. Under the current and proposed prices each commercial and foreign payload contributes to the fixed costs of U.S. Government payloads. Any pricing structure that priced the shuttle out of the market would result in reduced commercial and foreign flights and thereby the need for greater budgetary contributions for NASA and other Governmental payloads.

An analysis conducted by the McDonnell Douglas Corporation illustrates the sensitivity of commercial space endeavors with space transportation costs. At the 1980 Phase I Shuttle price of $31 million per flight, the McDonnell Douglas Corporation identified eleven natural biological products for production on the Shuttle. According to MDC, the phase II Shuttle prices of $71 million cut those candidates down to six. At the proposed phase III price of $87, MDC analysis indicated the number of commercial viable products would drop to four.

We, therefore, believe that high Shuttle prices (within the context of the Congressional Budget Office Shuttle pricing study) would have an adverse impact on our efforts to promote the commercial use of space.

Air Force CELV

Question: It has been suggested that a Shuttle-derived configuration of an ELV that has growth potential could be developed by the late 1980's — early 1990's timeframe. Do you concur with this assessment?

Answer: NASA proposed a Shuttle-derived configuration known as SRB-X in response to the Air Force solicitation for a CELV. In the context of that procurement (award in early CY 1985), NASA indicated first flight in late CY 1988. In any other procurement context the date would range from the early to mid 1990s, depending on the configuration selected and the funding profile.

Shuttle Centaur Upper Stage

Question: As a result of your review, what have you identified as the magnitude of the overrun in the development program, and, in the production program? Would you break out the estimates of the production program increases in materials, labor and another major costs? What portion of the overrun will NASA be paying for? Where will the money be coming from for NASA to pay for the overrun?

Answer: The review of the Shuttle/Centaur overrun has not been completed at this time, although it does appear that our earlier, quick-look estimates of the problem may have been low. We anticipate the NASA position will be available about May 1, at which time we will provide answers to your specific questions.

Question: I understand there is a financial incentive in the General Dynamics contract to complete the development program within schedule and to support the two launches in May. Are these incentives included in your overrun estimates. If so, why? Are there any financial penalties for a major development cost increase while the schedule is adhered to? Are there any technical difficulties that have been identified for the Centaur G or G-Prime?

Answer: The contract does include incentive fees, award fees, and a bonus to be paid upon successful completion of the two planetary missions. Since the award fee and bonus are essentially based on performance, it is still possible for the contractor to earn these fees. Therefore, these total fees are still in the new estimates. The incentive fee will be reduced by the amounts allowed on the contract to reflect their share of the overrun, and this reduced incentive fee will be reflected in the new estimates. The Shuttle Centaur program has experienced the typical technical problems that would be expected in developing flight hardware. One item that has been recently identified is that a minor design modification may be necessary to the flight vehicle LH2 forward bulkheads based on results of our structural test program at Sycamore. A second problem encountered is one of long standing, and that is the acquisition of high reliable electronic piece parts. This is a generic problem that is experienced throughout the space industry. Both of these problems are in work and are not regarded as an impact to our schedule at this time.

Shuttle Market Position

Question: Earlier this year, you stated that there has been "severe erosion in NASA's position in the launch services market, principally because of competition from Ariane." While it has been stated that the European Space Agency wants no more than a third of the commercial launch business, do you expect this to remain the case?

Answer: Statements by Arianespace officials that they were seeking no more than one-third of the commercial launch market date back to 1980-81, when the estimates of launch demand that they (and all of us) were using were far higher than we now believe to be credible. Looking at Arianespace's behavior in the marketplace since then, we have come to the conclusion that the proportion of the market it was seeking roughly reflected the number of flights Ariane then needed to be an efficient operation. In the meantime, however, Arianespace's marketing effort has intensified markedly. They have often resorted to steep discounts in order to assure that their bids to launch customers undercut the Shuttle, even in the FY 1986-88 pricing period. We believe that Arianespace will price against all competition (Shuttle and U.S. ELVs) so as to capture its desired traffic level.

Because of the benefits to European industry (satellite and ground station manufacturers and suppliers as well as industry directly involved in the Ariane vehicle), Arianespace is motivated to capture as much of the market as it can up to the limits of its capacity.

Question: Another "competitor" to the Shuttle appears to be refurbished Air Force Titan II missiles. NOAA recently indicated that they would launch three of their satellites on these ELV's rather than remain with the Shuttle.

What reaction do you have to this proposal?

Do you believe, in terms of overall Federal cost, that this proposal is the most economical?

Answer: Refurbishing and using Titan II surplus military missiles as Expendable Launch Vehicles, to launch Defense Meteorological Satellite and NOAA-K, -L, and -M Satellites, is not necessarily the most economical means of accomplishing these missions. Our comparison of costs associated with Titan II launches versus shared Shuttle launches leads us to the conclusion that the most economical cost to the Federal Government is by utilizing the Shuttle and manifesting these payloads with other payloads planned for launch from VAFB.

Space Shuttle Flights in FY 1985

Question: Given your most current manifest, how many flights do you anticipate in FY 1985? How many do you anticipate in FY 1986? How many DOD flights do you currently have on the manifest for each year beyond FY 1985?

Answer: The current planning anticipates 9 Shuttle flights in FY 1985 and 14 flights in FY 1986 although we are evaluating the potential to add a flight in this timeframe or early FY 1987. In order to meet DOD requirements after FY 1985, we have scheduled 2.3 equivalent flights in FY 1986, 5.7 flights in FY 1987, and 8.0 flights in FY 1988.

Second Source

Last year, NASA solicited "expressions" of interest in a second source for the Solid Rocket Motors used in the Shuttle Program.

Question: What is the status of this process?

Answer: Four contractors responded to our "Sources Sought" announcement on February 1, 1985. After our assessment of the responses, the contractors were asked to provide their costs in a standard format by March 7, 1985. Interviews with each contractor to review their responses were held March 20 and 21. The Ad Hoc Study Committee will complete its assessment and be prepared to brief the Administrator by the end of April.

Orbital Maneuvering Vehicle

Question: NASA is requesting $25 million to initiate the remotely piloted Orbital Maneuvering Vehicle (OMV) to deliver, retrieve and service payloads beyond the operating range of the Space Shuttle. What is your estimate for the total project development cost and timeframe? Would you briefly describe the operations you envision for the OMV and the range extension provided to the Shuttle?

Answer: The estimated cost for the Orbital Maneuvering Vehicle (OMV), Design, Development, Test and Evaluation (DDT&E) and first flight unit is $375-450 million. The procurement effort would follow completion of current definition efforts and start this fall. The first flight is planned for early 1990.

The OMV is a reusable, remotely piloted vehicle that increases the "reach" of the STS by moving payloads to and from the STS. It moves these payloads under ground control, freeing the Shuttle crew to perform other operations during payload transportation to and from the STS. It eliminates the need for STS energy and crew time in making these local stops. The OMV can, for reference, move a 5,000 pound satellite in a roundtrip orbit altitude change of about 1200 nmi., or effect about a seven degree orbit plane change, so it has quite a large orbital maneuvering capability.

The primary use of the OMV will be in bringing satellites to the Shuttle (or later Space Station) either for servicing by the crew or return to Earth. In particular, the OMV is expected to play major roles in the Hubble Space Telescope (HST), and future Earth observation, communications, and science spacecraft. Our recent success in saving three satellites, along with the logically expected increase in these mission operations that success brings, strongly supports a need for additional capability to bring and return future servicing "customers" to the STS. This is particularly true in polar orbit operations, where we will soon be operating through Shuttle launches from its

Western Test Range (WTR). The Shuttle has much less payload capability from the WTR in polar orbit, since the rotation velocity of the Earth (available in the ETR equatorial orbit launches) is not available. The OMV will efficiently increase the orbit payload delivery/retrieval capabilities of the STS polar orbits.

The OMV also permits future launch of payloads from the STS without their own propulsion/fuel systems, thus reducing satellite cost. Some payloads, such as our potentially promising commercial materials processing application, do not want integral fuel tanks due to "slosh" perturbation; yet want periodic removal of products and resupply of materials. The OMV will perform these operations from the STS beginning in 1990 and be fully checked out to serve a possible role with the STS in assembly of the Space Station. We envision a need for a second OMV to then be stationed at the Space Station for maneuvering operations, along with the original STS-based OMV which will handle orbits not accessible from the Station and its OMV.

Orbiter Production Capabilities

Question: What will be lost for every year we delay the decision to proceed with the production of the fifth Orbiter?

Can you identify what will it cost to maintain the orbiter production capability to produce a fifth orbiter in the early 1990's?

Answer: The Orbiter production lines at the major structural spares subcontractors will begin closing down with the delivery of the structural spares mid-fuselage in FY 1986, and concluding with final delivery of structural spares elements in late FY 1987. The subsystem production capability is coupled with the Orbiter operational logistics program and is ongoing for the majority of the subcontractors. Therefore, although certain skills will be lost at Rockwell International and selected subcontractors, the nucleus for an OV-105 production capability will be maintained by our current programs through the current budget year. After this time, our studies show the total costs for a fifth Orbiter for start-up, inflation, and reserve would increase about $200 million for each year.

To produce a fifth Orbiter for delivery in 1991 would require a new start authority in FY 1987 at approximately $165 million and approximately $1.9 billion total above the $460 structural spares already in the budget. Currently authorized structural spares and logistics programs will maintain production capability through FY 1986.

Filament Wound Case

The filament wound case for the Shuttle solid rocket was initiated by NASA to reduce vehicle weight and increase payload capability. On October 25, 1984, there was a full duration test firing of the solid rocket motor with the filament wound case.

Question: What is the present payload improvement that can be expected from the filament wound case?

What is the level of funding requested for the filament wound case in FY 1886?

Do your engineers indicate that the filament wound case can be refurbished after landing in the ocean?

What is the limit to the number of times this filament wound case can be flown and how does this compare to the steel case?

What is the cost differential in the purchase price of the two cases?

What is the total development cost?

Answer: A payload improvement of 4600 pounds is expected from the filament wound case.

The total FY 1986 funding request for filament wound case development and system integration activities is $41 million.

The filament wound case has been designed to withstand the water impact loads. A data base has also been accumulated on sub-scale test articles to assess the damage tolerance and acceptance criteria for the filament wound cases. A vigorous sub-scale and full scale (with expanded segments for static testing) is currently being conducted to assess the ability of the case segments withstanding this hydro-lasing removal of insulation, and the thermal cycling effects of re-insulating and propellant curing. The engineering assessment, at this time, is that the case segments can have the potential to be refurbished for re-use. Our assessment will continue through the recovery and analysis of several flights.

The steel case is planned for use in twenty flights (19 re-uses). The filament wound case flight re-use is unknown at this time.

The filament wound case purchase price is about double the price of the steel case for an SRM. This is based on a filament wound case production rate of 1 1/2 flight sets per year and is consistent with the FY 1986 Budget request and its runout.

The total of all development cost is expected to be $282 million. This costs includes design, development and testing; fabrication and delivery of three flight units from Hercules to Thiokol; and systems integration activities at Johnson and Kennedy Space Centers.

Tethered Satellite System

Question: NASA has requested $56.0 million for the development cost of the Tethered Satellite System of which $21 million is requested in FY 1986. The $56 million for development is exclusive of the science instruments, for which a total of $9.0 million has been requested. The Italian government is participating in this project and the first flight is scheduled for 1988.

What is your estimate of the NASA development program costs?

What proportion of the total development costs is it anticipated that the U.S. will provide?

Answer: The development cost of the Tethered Satellite System for which NASA is responsible (exclusive of the science instruments) is $56.0 million.

The U.S. development cost estimate for the Tethered Satellite System including the NASA science instruments is:

NASA Tether deployer and integration	$56.0 million
NASA science instruments	9.0 million
TOTAL	65.0 million

The Italians, responsible for the development of the satellite and the core equipment science instruments, are planning a similar amount. NASA is, therefore, providing about 50 percent of the total development costs.

Question: Would you please provide, for the record, a description of the key hardware development items, identifying any items that require significant technological breakthroughs and briefly describe the operation of the system?

Answer: The Tethered Satellite System is a cooperative U.S./Italian development, which will provide a unique Shuttle facility that can fly repeatedly as a mixed cargo on the Space Shuttle and deploy payloads up to 100 km above or below the Orbiter for measurements and observation in the lower thermosphere and ionosphere. The overall system consists of a deployer, being developed by NASA, and a satellite system being developed by Italy. The program objectives are to demonstrate the successful operation of a satellite tethered from the Shuttle, to qualify the interaction between the Tethered Satellite and space plasma in the presence of an electric current conducted through the tether, and to develop a reusable facility capable of supporting a broad range of tethered satellite applications. The NASA budget estimate is for one Tethered Satellite Mission demonstration to be conducted in 1988.

Aerospace Safety Advisory Panel

Question: Do you agree with their evaluation that a "number of hardware items, especially in the avionics area,... are obsolete and must be replaced or significantly upgraded"?

Answer: We currently have underway, or scheduled to be done, a number of hardware modifications which we characterize as improvements. The specific justification for these changes vary with each particular item. Some are the result of changing or additional requirements, some are product improvements, and some based on actual flight data which differs from our design assumptions.

We feel in certain areas that the systems need upgrading, not necessarily because they are "obsolete" but because, in the case of the General Purpose Computer (GPC), the system has become overloaded in both time and functions. We are procuring new GPC which are about three times faster, and have over twice the memory, at a cost of about 40 percent of the existing ones.

Another area of improvements is the Inertial Measurement Unit. We are replacing these items because of logistical cost effectiveness. The star-tracker is being evaluated for similar reasons. There will be cases where other systems will be closely examined as requirements dictate.

NASA does not feel there are safety of flight issues involved in any of these areas.

Question: Would you comment on the seriousness of this problem and, also, on how long it will exist?

Answer: Cannibalization has been necessary on a selected basis to meet flight schedules when critical parts were not available. We recognized this would probably be the case until the spares deliveries reached the planned levels as the logistics program matured.

Now that the spares deliveries are approaching the planned 90 percent level, cannibalization is being reduced significantly. We are currently able to provide spares at the 86 percent level from our logistical spares program.

Some "out of stock" conditions will always exist, however, due to higher than planned consumption of individual line items. It is prohibitively expensive to attempt to purchase support capability to 100 percent, but we have ordered those items which our studies show will be the most needed items.

We feel our approach is the most cost prudent method of maintaining our goals and objectives within reasonable budgetary limitation and feel that the problem will continue to decrease.

Question: What has been NASA's response to the Panel Recommendation?

Answer: The ASAP recommended a committee of Government and industry experts be formed to study the landing gear and brakes. The review recommended by the panel was held for the brakes and the findings of the expert committee were discussed with the Panel on April 26, 1984, at the Johnson Space Center. The conclusions reached by the committee's board were: (1) no flight safety issue exists with the current design; (2) the Board made eight recommendations to improve and test the brakes, which are all in process of implementation.

It is the program's understanding that the ASAP members present during the April presentation were satisfied with the adequacy of the brakes.

The ASAP recommendations to provide a four-wheel assembly on each landing gear, lengthen the nose landing gear and increase the brake capacity would all involve major redesign of the landing gear/brake system. The landing gear has been reviewed numerous times during Orbiter structural reviews, and adequate margins of safety exist for all expected flight conditions with the existing landing gear.

DOD/NASA Cost Sharing

Question: Please list all of the FY 1985 and FY 1986 programs in which NASA and the Department of Defense are proceeding with jointly funded technology programs and the DOD cost contribution of each.

Answer: See below.

NASA/DOD Jointly Funded Aeronautics Technology Programs
($ in millions)

	Estimated DOD Funding FY 1985	Estimated DOD Funding FY 1986
Research and Technology Base	6.5	6.3
Fluid & Thermal Physics Research and Technology	0.9	0.7
Applied Aerodynamics Research and Technology	1.0	1.0
Materials & Structures Research and Technology	1.5	1.5
Controls & Guidance Research and Technology	0.3	0.3
Propulsion & Power Research and Technology	2.8	2.8
Systems Technology Programs	37.8	28.8
Rotorcraft Systems Technology	18.0	13.6
RSRA/X-Wing	15.0	9.0
Convertible Engine	0.8	2.6
Rotorcraft Technology	2.2	2.0

High Performance Aircraft Systems		
Technology	19.8	15.2
X-29A FSW	13.2	9.2
AFTI/F-111 MAW	2.1	1.8
Oblique Wing Technology	1.0	---
Oblique Wing Research Aircraft	---	2.7
F-14 ARI	0.3	---
AFTI/F-16	3.2	1.5
TOTAL	44.3	35.1

Space Station

Question: In your opening statement, you refer to the Advanced Technology Advisory Committee (ATAC) established to report on the potential for advancing technologies in automation and robotics in relation to the Space Station. We will be having the Chairman of the Committee, Aaron Cohen, and the Chairman of the Steering Committee, Dr. Robert Frosch, testifying on the report in the second part of this hearing. How will NASA insure that the aerospace industry working on the Space Station will utilize the recommendations related to automation and robotics in the definition and preliminary design studies?

Answer:

o NASA is preparing an implementation plan, based on the ATAC report, that will be given to all Phase B contractors during negotiations.

o During Phase B, the contractors will, in effect, be competing for the C/D program.

o The quality of the automation and robotics plan that they will be required to prepare during the Phase B effort will be a discriminator in selecting a Phase C/D contractor.

o The implementation plan referred to includes guidance given to NASA by an independent (non-aerospace) university and industry panel that NASA formed to evaluate the issue. Their report will be submitted to the Congress in addition to the ATAC report.

Question: One important aspect of the Space Station is the International Cooperative Effort that it represents. What firm commitments by other nations have been made to date? What general agreements do you expect during FY 1985 and FY 1986?

Answer: At the ESA Ministerial Conference in Rome on January 31, 1985, the European ministers agreed to accept President Reagan's invitation to cooperate in the Space Station Program. For Phase B, 80 million accounting units have been approved for ESA definition studies over the next 2 years (approximately $65 million). Development funding in the Ministerial Resolution is 2.6 billion accounting units (over $2 billion). In Japan, the Finance Ministry has forwarded a request for initial Space Station Phase B funding to the Diet. This amounts to approximately $6 million for the first year. In mid-March 1985, Prime Minister Mulroney of Canada accepted President Reagan's invitation to participate in the Space Station Program. An overall Canadian Space Plan containing a request for initial Space Station definition funding has been prepared and submitted for government approval. This plan would provide approximately $22 million for Space Station studies for the next two years.

Agreements in the form of Memoranda of Understanding (MOU) will be executed with ESA, Japan and Canada for Phase B (April 1985-April 1987). These MOU's will coordinate Phase B studies and establish mechanisms to reach agreement on cooperative elements.

Question: How do we effect a true working partnership with these nations while limiting the transfer of key computer and space technologies as well as assuring confidentiality of proprietary data for potential commercial customers?

Answer: The Space Station Memoranda of Understanding (MOU) with our potential international partners provides for the exchange of that data necessary for partners to accomplish the cooperative project. Information which is necessary for the effective conduct of the cooperative program -- configuration and systems requirements information related to the interface -- will be provided. Provisions for the exchange, if necessary, of proprietary or protected data under protective conditions are also included in the MOU. At the same time, it is understood by both the U.S. and its potential partners that certain data such as industrial trade secrets will not be exchanged and steps will be taken to prevent the unwarranted transfer of technology.

Question: Please provide, for the record, a description of the process that you plan to implement to identify and select research activities in support of developing robotics and/or new automated systems for the Space Station. What amount is planned to be available for these activities in FY 1986 of these items?

Answer: We are currently conducting a value assessment of all of the technology recommendations contained in the report that have been submitted to NASA by Cal Space entitled, "Automation and Robotics for the National Space Station Program." This value assessment will prioritize the technology endeavors from the standpoint of the degree of leverage that each endeavor can exert in either reducing operating costs or enhancing the Space Station efficiency. This assessment will be used in structuring the automation and robotics portion of our advanced development and focused technology budget. The precise data is not available now, but will be determined by the time we submit the FY 1986 Operating Plan to the Congress in the fall of CY 1985.

Question: Mr. Beggs, let me read you a brief excerpt from the Automation and Robotics Panel administered for you by the California Space Institute of the University of California.

"The Automation and Robotics Panel concludes that Congress was correct in its initial judgment. NASA can indeed significantly improve the effectiveness and reduce the cost of Space Station operation by promoting the development and use of advanced automation and robotics.

All major systems and most subsystems of the Space Station can be advanced over implementations in existing spacecraft. Capabilities and efficiencies will expand if the program is designed, from the beginning, to accept and absorb advances in automation and robotics. Space Station will then be able to accomplish an even wider range of missions, and do them better and more cheaply, than if it made only limited use of advancing technologies.

Also, NASA is uniquely positioned to advance automation and robotics in the national context.

The Panel concludes that the Space Station Program can be related more intimately to the mainstreams of American life and technology than were past space activities."

Would you please provide NASA's reaction to the conclusions of the panel?

Answer: NASA essentially agrees with this assessment. The Space Station, since it will be designed as a permanent facility and will be modified in discrete stages, will have the capability to incorporate automation and robotics elements that will enhance the Space Station's efficiency. As a matter of fact, in the ATAC report, the following statements are made that generally are an adherence to the quotation that has been cited. For example, page 4 of the ATAC report contains the following statements:

These advances could have benefits not only for space activities but also for U.S. technology in general.

For space activities, the benefits could be:

o Increased productivity--with astronauts functioning as managers on behalf of station users rather than as operators carrying out routine functions.

o Increased responsiveness to innovation--with the automated Space Station being more flexible and adaptable.

o The ability to perform with robots and teleoperators tasks unsuited to humans alone--such as the assembly of large structures.

For the U.S. economy, the benefits will be:

o A Space Station more suitable for commercial ventures with flexible and reliable systems and crew time for management actions.

o The application of advances in automation and robotics stimulated by space ventures to terrestrial situations in settings ranging from the factory floor to the homebound elderly and on to the bottom of the sea.

While it is clear that the Space Station will provide a focus for the advancement of automation and robotics, it is not clear that NASA's budget can provide a general advance in this field in the national context.

TDRSS

Question: Your prepared opening statement mentions a fact well known to me--that the launch of TDRSS-2 was deferred due to a problem in the timing circuits of the spacecraft. What will be the impact of the delay in the completion of the TDRSS operational capability?

Answer: NASA and our contractors developed a plan to modify the remaining five spacecrafts. The launch and checkout of the next two spacecrafts are required to provide an operational system. The scheduling of these launches has not yet been determined, but the intent is to provide launches as early as possible consistent with overall Shuttle commitments. There are no critical user impacts identified at this time; however, coverage support to programs will be continued until a full capability is available.

Question: The three TDRSS spacecrafts, when operational, will provide tracking and communications for low Earth orbit missions replacing the existing ground network made up primarily of the world wide space tracking and data network. Will any ground network stations that were scheduled for closing have to remain open to provide tracking and communications coverage?

Answer: Ground network stations at Hawaii; Guam; Ascension Island; Santiago, Chile; Dakar, Senegal; and Yarragadee, Australia will have to be extended. The closure date will be evaluated and is dependent upon establishing a fully operational TDRSS.

QUESTIONS SUBMITTED BY SENATOR LAUTENBERG

Academic Support

Question: Do you perceive a need for modernizing equipment and facilities at our major universities for space-related research?

Answer: Yes, NASA perceives the need for providing state-of-the-art equipment at our major universities for space-related research. In addition, our participation on both internal and interagency study groups suggests that the need for modern equipment is still widespread and further decline will compromise the productivity and quality of the research and graduate training performed at such institutions.

Question: Does NASA plan to address this need in any specific way? As you may know NSF has commenced a program directed specifically toward modernizing academic equipment and facilities.

Answer: NASA's current estimate of university research funding for FY 1985 is $270 million and estimates for FY 1986 are in he $305 to $315 million range. Based on previous analyses of that expenditure, we estimate that approximately 10 percent or $27 million and $30 million respectively, will be used for modernizing academic research equipment and related facilities through grants and contracts awarded to universities for research.

NASA is aware of the National Science Foundation, Department of Energy, and Department of Defense's instrumentation programs. Like those agencies, it is our opinion that it is in NASA's best interest to tie our support for the modernizing of academic research equipment and related facilities to the research programs that we sponsor at the universities and, therefore, directly to our university grant and contract awards.

Intermittent Combustion Engine (Rotary)

Question: Please describe the status of research on development of a stratified charge,rotary engine for use as a new advanced powerplant for general aviation. Please describe NASA proposed activities and effort in this area. Do you agree that there exists a need to develop new, advanced powerplants for general aviation--powerplants that are smaller, lighter, that are more fuel-efficient? Do you agree that the rotary engine provides the promise of meeting that need?

Answer: The ongoing program is now focused on the stratified charge rotary engine combustion process along with other technology thrusts such as thermal barriers (to reduce heat rejection), seals and tribology and turbocharging and turbocompounding.

The current work consists of analytical and experimental activities to better understand the fuel injection and combustion process. A High-performance stratified-charge test rig is operating satisfactorily on jet-A fuel, and with less than 100 hours of operation it has demonstrated efficiencies approaching the highly developed gasoline engines that are currently in production. Work will continue to improve the efficiency by use of thermal barriers that are now being investigated. The ceramic work in small gas turbines will also be applicable to the rotary engine.

We agree that the need exists for a new, more efficient light aircraft engine. We further believe that the rotary engine is a particularly effective configuration for light aircraft. It provides smaller frontal area, reduced vibration, highly competitive fuel economy, a potential for lower manufacturing costs and most importantly the ability to adapt to any of the commonly available hydrocarbon fuels.

However, we note that the general aviation industry must provide the necessary support for the development of new or improved commercial products.

Question: Assistant Administrator Murphy in a letter to me expressed confidence that there would be available resources to permit timely development of the rotary engine. What is your timetable? What resources are needed? How much do you propose spending?

Answer: The currently anticipated $2.5 million per year NASA funding rate together with the highly cooperative relationship with Deere and Co. will permit technology readiness by at least 1989 for the stratified charge rotary engine. This engine will be capable of burning readily available kerosene-based jet fuels and of providing significant improvements in fuel economy, installability, and emissions relative to current reciprocating engines.

Impact of Budget Freeze on NASA Programs

Question: The Senate Budget Committee has just approved a budget plan calling for a freeze at current levels for most nondefense programs. What would the impact of such a freeze be on NASA's activities.

Answer: NASA's FY 1986 budget request is already nearly level with the FY 1985 after providing for inflation.

A freeze at the FY 1985 level would reduce the NASA request by about $400 million from the FY 1986 request. A reduction in funding of this magnitude after the absorption of the additional requirements would require a major restructuring of the entire NASA budget because the magnitude of the adjustment cannot be made without impact to previously approved on-going programs.

The newest projects with the least investments, such as the OMV, ACTS, ATP, and Commercial Use of Space would probably be delayed or deferred. Finally, a reduction of this magnitude would have a ripple effect throughout the NASA organization through the breakup of research teams, changes in detailed project schedules and deferral of testing and integration activities which, when combined with the effects listed above, make it a certainty that a budget freeze at the FY 1985 level would have a major adverse impact on the National Aeronautics and Space programs.

Question: Under the President's proposal, the total NASA budget would increase almost $395 million, from $7.491 billion (excluding a $23 million FY 1985 supplemental) to $7.886 billion. The increase in the Research and Development account alone is $495 million (which is partially offset by decreases in Shuttle Production and Operations Capability) which rises from $2.423 billion FY 1985 to $2.882 billion in FY 1986.

A major part of this increase is related to the Space Station ($230 million). If you have to live with a freeze, wouldn't it make sense to defer some or all of these long-term design activities and proceed with projects that are already underway?

Answer: If the FY 1986 NASA appropriation were frozen at the FY 1985 level, the most recently initiated approved projects with the least investment would be deferred or delayed. The contracts for Space Station definition studies are planned to begin in April, 1985, and disrupting this activity by stopping it for any length of time would result in the possible breakup of contractor teams and the loss of valuable program momentum. The Space Station is an international activity and the Memorandums of Understanding for definition activity are expected to be signed with the Europeans, Canadians, and Japanese this spring. If we were to withdraw all funding in FY 1986 for Space Station, this would be a clear signal to our partners that our commitment is not serious and could cause them to withdraw their valuable contributions from the program.

Materials Processing in Space

Question: The Materials Processing in Space account would increase by $7 million to $34 million). How much of this do you plan to devote to crystal growth research? Are other pharmaceutical-related experiments planned?

Answer: Our program in protein crystal growth started in FY 1984. In FY 1986, we plan to allocate approximately $800 thousand to the University of Alabama in Birmingham for a protein crystal growth experiment, and our current plan assumes that an additional $125 thousand will be allocated for supporting ground-based theoretical studies.

Additional experimentation is planned using the McDonnell-Douglas Continuous Flow Electrophoresis System and the

Isoelectric Focusing System. Recirculating Isoelectric Focusing System is currently being studied and a development start is planned for FY 1986. In addition, a bioreactor system is being developed for flight in late 1987, and a blood storage experiment will be flown in late 1985. The total NASA funding for pharmaceutical-related STS flight experimentation in FY 1986 is approximately $6 million.

Advanced Communications Technology Satellite (ACTS)

Question: As you know, the authorization for NASA last year called for a launch date for the Advanced Communications Satellite in 1989. Are you on schedule at this point? Will the funding you request be sufficient to maintain the required timetable?

Answer: ACTS is on schedule with the current launch scheduled for September 1989. The current funding level will maintain this schedule.

Question: You mention the need to remain competitive in this area in your statement. Could you amplify the point? What competitive challenges do we face? What is the status of European and Japanese programs.

Answer: The United States cannot remain competitive with other nations in all areas. But Communications Satellite technology is clearly one area where we are ahead and where our national security and economic interests demand that we stay ahead.

Our balance of trade experience with Japan and Europe indicates that superior technology is one alternative to trade tariffs. Japan has a stated national goal to leapfrog U.S. technology in communications as well as automobile and steel making. France and Italy also have goals to compete with the U.S. with communications satellites just as they have done in launch vehicles.

The Japanese have an integrated program in space communications which includes advanced satellite development with the experimental Japanese CS-1 satellite (launched on December 14, 1977) designed to provide six channels using fixed spot beams in the 30/20 GHz band. Two operational domsats were launched by Japan in February and August of 1983 and these also operated with spot beams and in the 30/20 GHz band. With an improved launch vehicle capability programmed for 1986, it is clear that Japan could offer domsat or direct broadcast satellite turnkey systems by 1988.

The Italian government is pursuing 30/20 GHz pre-operational satellite (ITALSAT) which is an aggressive commitment to communications using advanced technology which will operate at Ka band. The ITALSAT system is expected to be launched in the 1987 to 1988 time frame and to give Italy a unique heavy trunking capability in the late 1980's. The current understanding is that ITALSAT will have a regenerative repeater used to interconnect narrow spot beams covering Italy. Onboard switching at baseband will allow use of satellite-switched time division multiple access with burst rates of 150 million bits per second. While the satellite switch technology is not as advanced as that used by ACTS (which allows onboard message storage and interconnectivity of individual circuits between scanning spot beams), it is a vital link toward the next generation of advanced communications satellites.

France recently sold ARABSAT, the first non-U.S. built domsat. They also have an ambitious R&D program.

QUESTIONS SUBMITTED BY SENATOR DOMENICI

Freeze at FY 1985 BA Levels

Question: What would be the effects of a funding freeze at FY 1985 BA levels be on NASA? Does this answer include an assumption that costs for the fourth shuttle orbiter will decline as orbitor production is completed?

Answer: NASA FY 1986 budget request is nearly essentially level with FY 1985 after providing for inflation. Our FY 1986 flexibility has already been eliminated by the absorption of about $400 million of requirement that, for the most part, were not planned. These requirements include a reductin inn planned Shuttle reimbursements causing an increase in appropriated fund requirements ($140 million), the addition of the ACTS and ATP programs ($118 million), establishment of the Commercial Use of Space Program ($30 million), early payment for the TDRSS to the Federal Financing Bank consistent with Congressional guidance to make such payments to reduce interest costs ($30 million), provision of an upper stage for the sixth TDRSS and ACTS spacecrafts ($26 million), initiation of the OMV ($25 milion) and augmentation of various Research and Analysis activities consistent with Congressional direction.

A freeze at the FY 1985 level would reduce the NASA request by about $400 million from the FY 1986 request. A reduction in funding of this magnitude would require restructuring of the entire NASA budget. The newest projects with the least investments, such as the OMV, ACTS, ATP, and Commercial Use of Space would probably be delayed or deferred. Finally, a reduction of this magnitude would have a ripple effect throughout the NASA organization through the breakup of research teams, changes in detailed project schedules and deferral of testing and integration activities which, when combined with the effects listed above, make it a certainty that a budget freeze at the FY 1985 level would have a major adverse impact on NASA.

Funding for production of Orbiter 104 drops off significantly in FY 1986 from previous years' levels reflecting the completion of work due to the planned delivery of Atlantis in mid-1985.

Question: What is NASA doing to reduce Shuttle operations costs?

Answer: In the area of Shuttle operations, significant efforts have been directed toward the objective of reducing costs. Facilities and associated ground support equipment have been planned and are being implemented that will optimize processing and launch at KSC. These initiatives have resulted in reducing Shuttle turnaround time from initial workdays of over 100 down to the 50-day range. The near-term goal is to continue to reduce to 35 days by early 1986, with a final goal of 28 days in later years. Reduction in turnaround time directly relates to a corresponding reduction in operation costs. To also reduce costs, consolidations of Shuttle operations activities and base support functions have been accomplished at KSC. These critical functions are now consolidated into two major contracts with the end result being additional reductions in costs.

Plans are in progress to consolidate various Shuttle operations at JSC which will, in turn, add to cost reduction. JSC is working to streamline their operations by transitioning from an Apollo-vintage system to one that takes full advantage of modern technology. They are moving from a process which was manpower intensive, customized for each mission, non-lead time critical, and which demanded limited flexibility, to one which is labor saving, hardware and software intensive, standardized wherever possible, and highly automated. This will:

1. reduce the manpower and lead time in mission planning,

2. reduce the manpower and preparation time for software products required per mission (on-board, mission control, and Shuttle Mission Simulators),

3. reduce the manpower and time required to reconfigure the facilities (applies not only mission-to-mission, but also to testing, training and software production), and

4. increase the flexibility and adaptability to changes in manifests, etc.

Thus, they expect to be able to accommodate the maximum projected flight rate with less total manpower, less total annual costs, shorter lead times, and in a manner more responsive to user needs and manifest changes. In addition, the risks of errors will go down, training will be of higher fidelity and with far fewer interruptions due to malfunctions and overloads.

Question: How many Shuttle flights does NASA currently estimate will occur in FY 1985 and FY 1986? If these estimates vary from your original budget plan, could you explain what impact this will have on Shuttle operational costs?

Answer: Currently, NASA plans to launch 10 flights in FY 1985 and 14 flights in FY 1986.

The recent delay in Shuttle flight missions does not result in identifiable savings in FY 1985. The FY 1986 budget assumed 4 flights through February 1985. Orbiter tile fixes, TDRS spacecraft anomalies and an accident at KSC have allowed NASA to launch only three. As the TDRS mission was not cancelled until late in the launch processing cycle, processing was essentially the same as though four missions had been flown. The TDRS mission was cancelled and an accompanying commercial payload substituted for a NASA payload on the next flight, due to launch in April. The remaining payloads (TDRS-B and LDEF Retrieval) have not yet been remanifested although the TDRS will probably fly later this year. The hardware from the cancelled flight will probably be used to accommodate LDEF retrieval and any other payloads made vulnerable by the rescheduling.

During the remainder of FY 1985, it is our intent to proceed with missions as rapidly as possible consistent with the requirements of payloads and the readiness of vehicles. The net result is that there is little likelihood of reductions in operations cost, and we anticipate an increase in cost associated with replacement of tiles and the resultant impact on completion of modifications to OV-102.

Question: How will the orbital maneuvering vehicle extend Shuttle capability?

Answer: The OMV is a critical element in future utilization of the full operational capabilities of the STS. The OMV is a reusable, remotely piloted vehicle that increases the "reach" of the STS by moving payloads to and from the STS. It moves these payloads under ground control, freeing the Shuttle crew to perform other operations during payload transportation to/from the STS. It eliminates the need for STS energy and crew time in making these local stops. The OMV can, for reference, move a 5,000 lbs. satellite in a roundtrip orbit altitude change of about 1200 nmi. or effect about a 7 degree orbit plane change, so it has quite a large orbital maneuvering capability.

The primary use of the OMV will be in bringing satellites to the Shuttle (or later Space Station) either for servicing by the crew or return to Earth. In particular, the OMV is expected to play major roles in the Hubble Space Telescope (HST), Advanced X-Ray Facility (AXAF), future Earth observation, communications, and science spacecraft. Our recent success is saving three satellites, along with the logically expected increase in these mission operations that success brings, strongly supports a need for additional capability to bring and return future servicing "customers" to the STS. This is particularly true in polar orbit operations, where we will soon be operating through Shuttle launches from the Western Test Range (WTR). The Shuttle has much less payload capability from the WTR in polar orbit, since the rotation velocity of the Earth (available in the ETR equatorial orbit launches) is not available. The OMV will efficiently increase the orbit payload delivery/retrieval capabilities of the STS for polar orbits.

The OMV also permits future launch of payloads from the STS without their own propulsion/fuel systems, thus reducing satellite cost. Some payloads, such as our potentially promising commercial materials processing application, do not want integral fuel tanks due to "slosh" perturbation; yet want periodic removal of products and resupply of materials. The OMV will perform these operations from the STS beginning in 1990 and be fully checked out to serve a later role with the Space Station.

Question: Why do we need to start the orbital maneuvering vehicle program now?

Answer: There are three significant reasons to start the

OMV now: 1) to permit availability for servicing missions such as the space telescope, if we experience unusually high solar activity, 2) to gain early systems operational experience with a remotely piloted vehicle for smooth transition to a mature STS operational capability status, thus permitting Space Station to benefit from the OMV's operational maturity, and 3) to provide extended capability to the Orbiter in the 1990s to increase its competitive edge in delivering and maintaining orbital payloads.

Many science and applications payloads cannot tolerate fuel sloshing perturbations of internal fuel systems. The OMV eliminates that problem, and permits substantial cost savings over a number of candidate systems.

Space Station

Question: When is the current operational date for Space Station? What effect would a reduction in Space Staion program funding have?

Answer: The Space Station is currently planned to be operational inn the early 1990's.

The effect of a reduction in Space Station program funding is depenent upon when, where, and how much is cut, but analyses of past programs, both manned and unmanned, have resulted in the following corollaries:

a) Within reasonable and practical limits, the larger the definition investment in a new project, the more likely it becomes that the requirements, scope, design and complexity of the project will be understood. This in turn, provides the foundation required for accurate planning and cost and resource estimates. A reduction in funding during the definition phase of the Space Station would very seriously affect the ability of NASA to adequately define the project. It could well result in inefficient cost and schedule plans. Moreover, a reduction in Space Station funding at this time would signal a stepping back from a program that represents a commitment by the United States to remain preeminent in space.

b) A reduction in planned funding during the development and production phase of a program such as the Space Station, particularly during the peak production years, initially results in a stretch-out of production phasing. This requires the extended retention of expensive production facilities and manpower, necessarily adding significantly to the total cost of the project. Failure to provide funding for the additional costs thus generated would have to be accommodated by reductions in planned capability, thereby reducing the utility of the Station to both the domestic and international commercial communities. The net result of a significant reduction in funding during the development and production phase of the Space Station could be a more costly, less capable Station that takes longer to complete.

Question: The recent Congressional Budget Office report, Pricing Options for the Space Shuttle, states that NASA's requirement that payment be spread over 33 months before a launch is a fiscally conservative policy. To what extent have you considered a more flexible pricing policy geared to market concerns?

Answer: The pricing policy for launch services which calls for a payment spread over 33 months was written early-on in the program with the intent of recoverilng expenditure outlays as they were incurred. NASA is now reviewing this policy, and while the time period of 33 months will be maintained in order to support an orderly process of launch planning the payment schedules may be adjusted to more closely reflect the incurrence of costs.

Question: Could you explain in more detail your plans to establish centers to "promote the commercial development of space"? Why are these centers needed? How many are planned and where will they be located? Could you explain why these centers are needed in addition to NASA's existing office of commercial space policy?

Answer: NASA recently invited industry, universities and others to respond to a Center for the Commercial Development of Space Notice of Opportunity. Based on our current plans, we expect to receive these proposals by June 1985, and award funding by early September 1985. A review panel comprised of representatives from industry, universities and government agencies will evaluate the technical and business merits of these proposals. NASA plans to fund three to six centers in FY 1985 at a rate of $500,000 to $1 million per center. NASA will be unable to determine the location of these Centers until proposals are submitted and evaluated by a review panel. Geographical distribution of federal funds will be a consideration in the selection process.

NASA's Office of Commercial Programs will serve as the focus for an Agency-wide program to help reduce the technical, financial, and institutional risks of doing business in space. As one initiative being implemented by the Office of Commercial Programs, the Centers for the Commercial Development of Space will enhance NASA's efforts to establish the research foundation that will stimulate private sector investment in space-related activities.

QUESTIONS SUBMITTED BY SENATOR LEAHY

Least Expensive Backup - Shuttle

Question: If Congress decides a backup for the Shuttle is needed because of doubts about its reliability, would it be cheaper to build another Shuttle or to produce additional rockets (Expendable Launch Vehicles)?

Answer: NASA believes the Shuttle has proven itself to be a safe and reliable launch system and that the projected four orbiter fleet is sufficient to meet the expected flight rate requirements through the foreseeablke future. Additionally, the Shuttle provides unique capability not available with expendable launch vehicles.

NASA is currently phasing out its expendable launch vehicles with the intent that, if viable, they will be continued as commercial endeavors. It would be expensive for NASA to maintain two different launch systems, therefore, if Congress decides additional backup is needed NASA believes the best choice would be to build another Shuttle.

Shuttle Delay Penalties

Question: If there is a delay in Shuttle launches caused by any failure of a system, does the contractor responsible for the delay incur any financial penalties?

Answer: If there is a delay in Shuttle launches caused by failure of a system, financial penalties are assessed the applicable contractor(s) in the form of a reduced award fee or incentive fee. In addition, the key contractors supporting primary program elements are now performing under mission incentive features. Each contract is unique in structure, but if the contractor is judged to be responsible for a significant delay or failure in the Shuttle program they will be penalized accordingly as specified in each contract.

Question: If so, what penalties have been assessed?

Answer: No significant failure of a system has caused a Shuttle contractor to receive a major mission related penalty (i.e., late mission performance or loss of mission). Reductions in award fees have resulted from inability to perform as desired, management performance being a key evaluation criterion.

Question: Please supply the Committee a copy of the launch processing contract.

Answer: A copy of the Shuttle processing contract with Lockheed has been supplied.

Space Science and Applications

Question: This Agency has done an outstanding job of developing the capability to get into space. Our leadership in space, I believe, is clear. In addition to demonstrating our world leadership, space program has two further objectives: (1) Expanding our scientific horizons; (2) Expanding economic opportunity on Earth by transferring space technology to the non-aerospace section of the U.S. economy. These objectives are accomplished in the Space Station and Applications program. In this program, there are no new starts--why not?

Answer: The Agency's budget includes a new initiative-the OMV. The FY 1986 budget considerations included several possible new starts. However, as a result of the overall federal budget constraints and other considerations, these proposals were not carried forward as agency new starts in the President's FY 1986 budget submission.

Budget Freeze

Question: Since 1980, NASA's budget, in constant dollars, has gone up by almost 12 percent. During the same period, funding for housing has gone down 48 percent and environmental protection is down by 26 percent. These are not hypothetical comparisons. Each of these programs is funded in this appropriations bill. Where will we have to make difficult trade-offs to avoid a presidential veto? Do you think the space programs should continue to increase when other high priority programs are being so deeply cut? If so, why? If we froze your budget at the 1985 level, what programs would you cut?

Answer: The level of each NASA budget request is a product of extensive review by the Administrator within the context of the entire proposed budget of the President. Economies of continued planned long-term commitments, effective utilization of the Nation's aerospace community and the appropriate and timely achievement of scientific and technological gains both immediate and long term all enter into the review process as well as the specific priorities of the Administration in determining the appropriate request for NASA. We do not feel that NASA has the appropriate information to comment on the priority the Administration places on NASA programs relative to other Federal programs.

NASA's FY 1986 budget request is already nearly level with FY 1985 after providing for inflation.

A freeze at the FY 1985 level would reduce the NASA request by about $400 million from the FY 1986 request. A reduction in funding of this magnitude after the absorption of the additional requirements would require a major restructuring of the entire NASA budget. The newest projects with the least investments, such as the OMV, ACTS, ATP, and Commercial Use of Space would probably be delayed or deferred. Finally, a reduction of this magnitude would have a ripple effect throughout the NASA organization through the breakup of research teams, changes in detailed project schedules and deferral of testing and integration activities which, when combined with the effects listed above, make it a certainty that a budget freeze at the FY 1985 level would have a major adverse impact on NASA.

CBO Proposed Cuts - Shuttle

Question: The CBO, in its "Spending Reduction Options" paper, includes a $260 million cut (10 percent) in the Space Shuttle budget in 1986, with a cumulative savings through 1990 of $1.3 billion. In its proposal, it notes that "NASA has consistently overestimated its technical ability to achieve a given flight rate."

What is your reaction to CBO's proposal of a 10 percent cut in NASA's Shuttle funding?

Answer: The following tables reflect NASA's FY 1986 Budget planning for Shuttle Operations:

	FY 1985	FY 1986	FY 1987	FY 1988	FY 1989	FY 1990
TOTAL SHUTTLE FLIGHTS	10.0	14.0	17.0	19.0	24.0	24.0
NASA	3.8	6.7	7.8	6.1	7.2	9.3
DOD	2.0	2.3	5.7	8.0	10.3	8.3
FOREIGN AND COMMERCIAL	4.2	5.0	3.1	3.6	5.0	5.2
REFLIGHT OPPOR.	—	.4	1.3	1.5	1.2	--
TOTAL SHUTTLE FUNDING	1832	2138	2325	2461	2534	2681
NASA APPROP.	1314	1725	1459	1283	1372	1456
DOD	330	155	531	771	647	732
FOREIGN AND COMMERCIAL	188	258	335	407	515	493
CBO PROPOSED SAVINGS	-	260	260	260	270	280

In responding to the CBO proposal several points need to be made.

1. Shuttle Operations involves a large amount of relatively fixed costs which are a function of achieving and sustaining the capability necessary to conduct Shuttle mission rather than the specific number of missions flown.

2. Total funding requirements for Shuttle Operations include the NASA appropriation and reimbursements received from the DOD and foreign and commercial customers.

3. The price charged commercial customers exceed the marginal cost to fly these missions. This means that a portion of the price paid by foreign and commercial customers is used to offset the fixed Shuttle Operations funding requirements. A reduction in foreign and commercial customers would actually increase Government funding requirements.

4. NASA funding requirements would increase with a reduction in DOD flights in a manner similar to the impact of reduced commercial flights, since they also reimburse NASA more than the marginal cost of a flight. However, the overall Government funding requirements could be reduced by decreasing the number of NASA or DOD missions, provided they are not flown by other means.

5. In the long run approximately $50 million can be saved by dropping a Shuttle flight assuming sufficient time is provided to adjust production and operational activities. This cost reduction is spread over three years with the largest portion being in the year of launch.

6. Due to contracting incentive arrangements and lead times with the major hardware suppliers, the savings in the near term will be significantly less than the $50 million.

Because NASA projects the price it charges foreign and commercial customers to exceed the costs of providing flight services, the budgetary savings of lowering the flight rate would be realized only if the U.S. Government were to cut back its own flights, rather than those supplied for foreign and commercial customers. We believe that approximately $250 million per year could be saved if Government missions were reduced by five per year starting in FY 1987 and they were not flown by other means. (Because of the contracting arrangements and the three year time phasing of the savings, the FY 1986 savings would be substantially less, approximately $120 million.) This would entail a reduction in planned Government flights by a factor of one-third.

The CBO report points out that the Shuttle system represents a large public investment that has just begun to pay off. The ratio of fixed to operating costs is very high, and therefore a disproportionate increase in services can be obtained with a relatively small percentage increase in costs. The specific impact would depend on the distribution of the flight reduction between NASA and the DOD, however, it is our belief that reductions of this magnitude could severely impact the NASA science programs and DOD programs.

Planetary Space Research

Question: In this time of budget constraint, we must be concerned about how our basic research dollars are spent. The National Science Foundation, in its 1986 budget has reordered its priorities to focus on research that is likely to enhance our economic competitiveness in the long term.

What possible economic spinoff can there be from planetary space research ~~which is~~ funded at $359 million in 1986 -- a $69 million increase over the 1985 level of $290 million?

Answer: The $69 million growth in the planetary program from 1985 to 1986 follows upon NASA's implementation of the recommendations of an ad hoc committee of the NASA Advisory

Council, the Solar System Exploration Committee (SSEC). Regeneration of the planetary program over the last three years has restored funding required to carry out the minimal recommended program.

Although the principal goals of the planetary exploration program are scientific rather than economic in nature, the SSEC specifically recommended that future economic possibilities be considered because, the committee recognized, the surface materials of the Moon and Earth-approaching asteroids may provide much of the basis of a future national economy in Earth orbit. The first anticipated utilization of such raw materials in near-Earth space will be for shielding and for the manufacture of liquid oxygen fuel. Such use promises to be far less costly and more efficient than bringing all supplies from the surface of the Earth. Based on such considerations, the SSEC, therefore, recommended that a new goal be adopted: "the development of a scientific basis for the future utilization of resources available in near-Earth space."

In the following era of the Space Station, economic benefits derived from planetary exploration are by no means fanciful and therefore have merited a balanced measure of support within NASA's Space Science and Applications Program.

Space Station and SDI

Question: The Air Force, under your new agreement, will control about one-third of the Shuttle cargo spaces. Do you expect that the Space Station will, likewise, have a significant military role? You have stated that the Space Station will be "a highly visible, yet peaceful, demonstration of U.S. leadership. Can the Space Station be a "peaceful demonstration" of U.S. leadership, if it is a base for Star Wars or other defense work.

Answer: NASA believes that the Space Station, as a civil endeavor, will not have a significant military role. As a national research and technology laboratory, with substantial international participation, the Space Station will indeed be a peaceful demonstration of U.S. leadership in space. NASA's plans for Space Station development do not envision the facility as a base for the Strategic Defense Initiative.

Aeronautical Research

Question: This budget includes $354 million for aeronautic research which funds basic research broadly applicable to commercial type aircraft. This budget increases by $12 million over 1985. What would be the effect of an overall freeze in aeronautic research?

Answer: The NASA budget request for $354 million for aeronautical research is to continue a program of technology development that has a 95 to 97 percent common applicability to both military and civil aviation. If NASA's Aeronautics budget is held at the FY 1985 level, the most likely impact would be on the Advanced Turboprop (ATP) program flight research phase.

CBO Proposed Cut - Aeronautical Research

Question: In addition to its space programs, NASA devotes about $400 million a year to commercially oriented aeronautical research and development. The research and development is done in several areas: noise, safety, fuel efficiency, and performance. The results of these programs are used by major airplane manufacturers. CBO has proposed terminating the fuel efficiency and performance research, arguing that there is sufficient private incentive to research these areas.

The savings would be $260 million in 1980, and $2 billion between now and 1990.

What is your reaction to CBO's proposal to reduce the deficit by $360 million reduction in aeronautic research in areas where it believes the aircraft manufacturers already have enough incentive to do research -- such as fuel efficiency and performance.

Answer: The estimate that NASA devotes about $400 million a year to commercially oriented aeronautical research and development is accurate only in the sense that over 95 percent of the NASA Aeronautics R&D budget has common applicability to both civil and military aircraft. The vast majority of NASA's aeronautical research and technology activities are long-term, high-risk and generic in nature. In 1982 and again in 1984, the GAO reviewed NASA's Aeronautics Program in depth and concluded (references MASAD-82-33 and NSIAD-84-120) that there was a very significant degree of commonalty (97 percent) for the applicability of NASA's research to military and civil aircraft, that only 1 percent was purely civil in nature and only 2 percent purely military. As an example, one of the major programs included in the aeronautics budget request for FY 1986 ($354.0 million). the Advanced Turboprop Program ($42.0 million for FY 1986) provides a common technology base for increasing fuel efficiency (thus the range and payload of both civil and military aircraft.) While broadly described as enabling a new generation of commercial transports, the C-130 airplane, a key element in the Air Force tactical transport fleet would, if equipped with advanced turboprops, have 33 percent greater speed with longer range for a substantial increase in mission capability. In the actions taken by the Congress with regard to the NASA FY 1985 Aeronautics budget, NASA was directed to reallocate $10 million from the R&T Base and to continue this program at a pace which would permit the first research flight to occur in 1987. The Advanced Turboprop Program has been used as an example to illustrate the point with a highly visible program element of the dual use character of the results of our aeronautical research.

General

Question: In the highlights of your budget (AS-6), you list the development of a "United States-Italian Tethered Satellite System" as one of your major 1986 objectives. Please describe what a "Tethered Satellite" is, and what unique mission it will perform.

Answer: The Tethered Satellite System is a cooperative U.S./Italian development, which will provide a unique Shuttle facility that can fly repeatedly as a mixed cargo on the Space Shuttle and deploy payloads up to 100 km above or below the Orbiter for measurements and observation in the lower thermosphere and ionosphere. The overall system consists of a deployer, being developed by NASA, and a satellite system being developed by Italy. The program objectives are to demonstrate the successful operation of a satellite tethered from the Shuttle, to qualify the interaction between the Tethered Satellite and space plasma in the presence of an electric current conducted through the tether and to develop a reusable facility capable of supporting a broad range of tethered satellite applications. The NASA budget estimate is for one Tethered Satellite Mission demonstration to be conducted in 1988.

Question: The Agency has studied, and continues to fund, a series of options for delivering payloads beyond the low Shuttle orbit. What missions will the orbital maneuvering vehicle (OMV) perform that cannot be performed by the expendable launch vehicles or expendable vehicles which take payloads from Shuttle altitude to higher altitudes? The OMV is one of the very few new starts. It will cost $400 million to complete between now and 1990.

Answer: The OMV will efficiently perform several missions that cannot be performed by expendable launch vehicles or expendable vehicles which take payloads from shuttle altitude to higher altitude.

The OMV is a reusable, remotely piloted vehicle that increases the "reach" of the STS by moving payloads to and from the STS. It moves these payloads under ground control, freeing the Shuttle crew to perform other operations during payload transportation to/from the STS. It eliminates the need for STS energy and crew time in making these local stops. The OMV can, for reference, move a 5,000 lbs payload in a round-trip orbit altitude change of about 1200 nmi or effect about a 7 degree orbit plane change, so it has quite a large orbital maneuvering capability.

The primary use of the OMV will be in bringing satellites to the Shuttle (or later Space Station) either for servicing by the crew or return to Earth. In particular, the OMV is expected to play major roles in the Hubble Space Telescope (HST), and future Earth observation, communications, and science spacecraft and observatories. Our recent success is saving three satellites, along with the logically expected increase in these mission operations that success brings, strongly supports a need for additional capability to bring and return future servicing "customers" to the STS. This is particularly true in polar orbit operations, where we will soon be operating through Shuttle launches from the Western Test Range (WTR). The Shuttle has much less payload capability from the WTR in polar orbit, since the rotation velocity of the Earth (available in the ETR equatorial orbit launches) is not available. The OMV will efficiently increase the orbit payload delivery/retrieval capabilities of the STS polar orbits.

The OMV also permits future launch of payloads from the STS without their own propulsion/fuel systems, thus reducing satellite cost. Some payloads, such as our potentially promising commercial materials processing application, do not want integral fuel tanks due to "slosh" perturbation; yet want periodic removal of products and resupply of materials. The OMV will perform these operations from the STS beginning in 1990 and be fully checked out to serve a possible later role with the STS in assembly of the Space Station.

Question: This Administration has consistently said that the Government cannot be successful in "picking winners" in choosing which industries should receive Government subsidies to compete overseas. Yet, the NASA budget includes a large "aeronautics research" budget which is justified because it "contributes materially to the enduring preeminence of U.S. civil and military aviation." Why should the Federal Government continue these large research subsidies to this industry when other industries -- machine tools, textiles, chemicals, steel -- receive little or no federal research support?

Answer: We certainly agree that the Federal Government should not pick "winning" technologies. The last seventy years of aviation have shown that the Federal Government investment in aeronautical R&T has been an efficient and effective mechanism for bringing the best skills of the Nation to bear on the most pressing needs. However, there are several unique characteristics of the aeronautical industry that dictate that the long standing Government/industry partnership be continued. In addition to its primary responsibility for defense, the Federal Government has responsibilities for safety certification, management of the airspace and environmental protection which require continued R&T to meet changing requirements and needs. The primary benefits of R&T in these areas accrue to the Government. This investment has been leveraged many times in returns to the country in the form of unquestioned superiority in military aircraft and a favorable trade balance that is exceeded only by agricultural products.

There is a strong common base of aeronautical R&T that underlies all future military and civil aeronautical system developments. While civil and military aircraft configurations often differ greatly, both benefit from diverse aeronautical R&T advances, providing a unique opportunity to compound the value of this research. Historically, civil aircraft have benefited from military technological advances in both airframes and propulsion. Increasingly, a reverse flow has been important, e.g., improved fuel efficiency, flight management systems, and lightweight structures.

Some additional factors which in combination distinguish aeronautics as an appropriate candidate for Federally supported R&T are: the extensive research facilities required with a replacement cost of approximately $6 billion; the lack of sufficient incentive for private sector investment in long term, generic aeronautical R&T stemming from the inability of the private sector to capture enough of the benefits from its own research efforts; the length of the R&D cycle for aircraft and the great length of the payback period; and the extensive breadth and depth of technologies required to produce superior aircraft.

The Aeronautical Research and Technology Policy report acknowledged these factors in concluding:

> "While the study group recognizes the urgent need to reduce government spending to achieve the objectives of the Economic Recovery Program, it unanimously concludes that a continued strong, government-budgeted program of aeronautical R&T is consistent with overall government priorities and should be maintained."

The Aeronautical Research and Technology Policy report also included a comparison of DOD and NASA support for aeronautical R&T. The resources for FY 1982 were noted to be: DOD, $400 million and 1900 people; and NASA, $480 million and 3800 people. In view of this analysis, NASA contributes roughly 65 percent of the manpower and 55 percent of the federal R&D funding required to provide the technology base for future military aircraft. While DOD resources are focused primarily on R&T closely related to identified military weapon systems, the NASA effort emphasizes technology opportunities for capabilities beyond identified mission needs and provides a basis for future systems.

Sufficient incentive to conduct the very board based research for future aircraft does not generally exist in the aerospace industry, nor does the industry have the necessary facilities for aeronautical research now vested in the NASA research centers. The civil industry devotes its available resources to investments in development ($2-3 billion for a new aircraft) which is near-term in scope and must utilize technologies already proven in the existing research and technology base. Development of new military aircraft is accomplished with U.S. Government funding including Government supported IR&D. The importance of the NASA role is captured in the recently released National Research Council Report, "The Competitive Status of the U.S. Civil Aviation Manufacturing Industry," which stated:

"The bedrock of U.S. leadership in civil aircraft is technology--its development and incorporation into new designs. That leadership need not be threatened provided that the U.S. maintains a vigorous program of research and development. The National Aeronautics and Space Administration (NASA) is the focal point of aeronautical R&D for both Civil and Military applications. The high cost of R&D and the massive facilities required for aeronautical R&D preclude any private enterprise from performing NASA's central role."

QUESTIONS SUBMITTED BY SENATOR DECONCINI

SIRTF

Question: I was pleased to see that NASA included Space Infrared Telescope Facility (SIRTF) as a mission candidate in NASA's budget justifications. If Infrared Astronomical Satellite (IRAS) is any basis for extrapolation (and I believe it is) SIRTF promises exciting future possibilities. I urge NASA to continue to push forward with SIRTF. Do you foresee any problems with SIRTF at this time?

Answer: Scientific investigations have been selected for SIRTF and the Science Working Group and the Ames Research Center are establishing the mission requirements, i.e., long duration free flyer mission or use of a space platform as part of the Space Station. These activities are proceeding well, and our present plans assume SIRTF Phase B studies in FY 1987-88 leading to SIRTF being a possible new start candidate in FY 1989.

AUTOMATION AND ROBOTICS

FOR THE NATIONAL SPACE PROGRAM

AUTOMATION AND ROBOTICS PANEL

California Space Institute
University of California

Preface

ORGANIZATION OF THE STUDY

In April 1984, the staff of the Senate Appropriations Committee and NASA agreed to establish a *Congressionally-sponsored study* to produce an automation report for the Space Station Program. Four groups contributed to the overall effort. NASA Headquarters was chosen to manage the study.

A special NASA team (the Advanced Technology Advisory Committee - ATAC) was to prepare a report on the automation study to guide the Phase B contractors. The ATAC report was to be submitted to the Congress by April 1, 1985.

To provide insight into practical applications, the Level A Space Station Program Office at NASA Headquarters organized a design team composed of five major aerospace corporations. They were charged with a six-month examination of how advanced automation and robotics could be used in actual Space Station subsystems. The design areas and contractors chosen were

Operator-Systems Interface (Boeing)

Space Manufacturing (General Electric)

Subsystems and Mission Ground Support (Hughes Aircraft Co.)

Autonomous Systems and Assembly (Martin Marietta)

Satellite Servicing (TRW Systems)

Level A also selected SRI International to form a technology team to review and assess the design concepts. This team provided assessments of the advanced automation and technology needs as determined by the mission contractors, and assisted the contractors with the integration of these technologies into the conceptual designs. In addition, SRI will provide an overall technology plan for the Space Station to be completed on March 1, 1985.

Finally, at the request of NASA, and with the agreement of Congress, the California Space Institute organized and administered the ***Automation and Robotics' Panel*** (ARP) which conducted the ***independent study***. The Panel was asked to provide guidance on the application of advanced automation and robotics to the IOC program, and how the Space Station program could evolve to accept advances in these fields. Guidance was also requested on how the Space Station program might help advance automation and robotics capabilities for the nation as a whole. This report is the result of that work.

Dr. David R. Criswell organized and directed the ARP. The subpanel chairmen (indicated in the membership list by chapter responsibility) assisted in Panel member selection and supervised preparation of the report. Specialists in the fields of automation, computer science, robotics, industrial development, and aerospace engineering from industry, universities, and the government constituted the full Automation and Robotics Panel (see membership list). Members were encouraged to consider and contribute to all sections of the report. Many others active in government, industry, and university research provided additional review activity, attended key meetings, and submitted position papers to ARP. They are recognized in the beginning of this report.

NASA and the California Space Institute (Cal Space) formed a steering committee. Dr. Robert A. Frosch, Vice President of Research for General Motors Corporation and a previous administrator of NASA, agreed to head the steering committee and maintain liaison with Congress and NASA. Prof. James Arnold and Dr. Charles A. Rosen were both on the steering committee and participated extensively in ARP. Dr. Rosen is the founder of automation and robotics research at the Stanford Research Institute (now SRI International) and is active in the development of several new advanced technologies critical to automation and robotics. Dr. Arnold is the director of the California Space Institute, a multi-campus research unit of the University of California, headquartered at the University of California, San Diego, on the campus of the Scripps Institute of Oceanography.

Special care was taken to coordinate ARP with NASA, the five design contractors, and SRI International. Key personnel in the Space Station level A Office at NASA Headquarters were invited to attend all major meetings of ARP. The chairman of ATAC and the Chief Scientist of the Space Station program were full members of ARP. Members of ATAC's Intercenter Working Group were invited to participate in major ARP meetings. At least two senior employees of the design contractors and SRI were also invited to attend all major ARP meetings. Dr. Criswell attended the eight meetings of NASA with the design and technology teams, as well as the coordination meetings of ATAC's Intercenter Working Group. Results of these meetings were distributed to ARP members. Both SRI and the design team members reserved modest allocations of manpower to assist ARP in specific work requests. All major ARP documentation was available to NASA, the design teams, SRI, and other interested groups. Senior staff members of Science Applications International Corporation (SAIC) worked with Cal Space as ARP members in the development of technical materials, attended the design team meetings, documentation and helped with the special projects.

ACKNOWLEDGMENTS

Many individuals and organizations contributed to the success of the Congressionally mandated automation and robotics study. The Cal Space Automation and Robotics Panel is deeply appreciative of the support and involvement received from Congress, NASA, and the five design contractors and SRI. The University of Texas cooperated with Cal Space in seeking some Panel members and hosting a work session. Many other organizations and individuals contributed their technical knowledge by participating in selected ARP meetings, submitting written comments, and reviewing various drafts. These individuals and organizations are recognized in the following section.

The California Space Institute is grateful for the extensive support provided to ARP by the Panel members, and the staff members of SAIC for their additional documentation efforts. The many ARP report drafts could not have been produced without long hours of work by the ARP support staff.

Membership

Automation and Robotics Panel Steering Committee

The Steering Committee provided top level advice on Panel membership, guidance to NASA and the Panel, and liaison with the Congress.

Dr. Robert A. Frosch (Chairman)
Vice President, GM Research Laboratories
General Motors Corporation
Warren, MI 48090

Professor James R. Arnold
Director, California Space Institute
University of California, San Diego
La Jolla, CA 92093

Dr. Charles A. Rosen
Machine Intelligence, Inc.
330 Potrero Avenue
Sunnyvale, CA 94086

Dr. David R. Criswell
Senior Technical Advisor and Program Director
California Space Institute
University of California, San Diego
La Jolla, CA 92093

Automation and Robotics Panel Members

The Automation and Robotics Panel members provided professional expertise in the wide range of topics encompassed by the fields of automation and robotics. They worked to identify major opportunities for applying new technologies and hardware to the planning of the Space Station, associated systems, and NASA's support operations. They also identified and explored those NASA activities with large potential impact on the national economy, either directly or by example. Members attended major meetings, authored report sections and reviewed the various drafts. Subpanel chairmen are indicated by chapter number.

Dr. James R. Arnold*	California Space Inst.
Dr. Robert Cannon	Stanford Univ. (Chapter 2)
Dr. Rodger Cliff	DARPA
Mr. Aaron Cohen	NASA Johnson Space Center
Dr. David R. Criswell	California Space Inst. (Chapter 6)
Dr. Doyle Evans	Los Alamos National Lab.
Dr. Sidney Firstman	Tech. Applications Lab., Georgia Tech.
Mr. Harold K. Forsen	Bechtel Group, Inc.
Alternate: Dr. Charles Cook	
Dr. Owen Garriott	NASA Johnson Space Center
Dr. David E. Groce	SAIC
Mr. Robert Hambright	Southwest Research Institute
Dr. Hugh Hudson	Univ. California, San Diego
Dr. Demetrius Jelatis	Sargent Industries
Dr. Michael Knasel	SAIC
Dr. Gene Konecci	Univ. Texas, Austin
Dr. Peter B. Linhart	AT&T Bell Labs.
Dr. Sanjay Mittal	Xerox PARC
Dr. Marvin Minsky	Mass. Inst. Tech.
Mr. John Niehoff	SAIC
Alternate: Dr. Harvey Feingold	
Dr. Roger Perkins	Los Alamos National Lab.
Dr. Marc Raibert	Carnegie-Mellon Univ.
Mr. Martin L. Reiss	United States Senate, staff
Dr. Charles A. Rosen*	Machine Intelligence, Inc.
Mr. Carl Ruoff	Jet Propulsion Lab.

Dr. Jack Schwartz	New York Univ.
Dr. Scott A. Starks	Univ. Texas, Arlington (Chapter 3)
Dr. Terry Triffet	Univ. Arizona (Chapter 4)
Dr. Richard Volz	Univ. Michigan (Chapter 7)
Dr. Bruce West	La Jolla Institute
Dr. Theodore J. Williams	Purdue Univ. (Chapter 5)
Dr. Michael J. Wiskerchen	Stanford Univ.

Contributing Participants

Several individuals assisted the Panel extensively.

Dr. Anne Beuter	Univ. Southern California
Dr. G. David Brin	California Space Inst. (Report Editor)
Dr. Richard Emmerson	Criterion, Inc.
Dr. James C. Fox	KMS Fusion, Inc.
Mr. Blake Hannaford	Univ. California Berkeley
Dr. M. Hyson	Consultant
Dr. George Kozmetsky	Univ. Texas, Austin (Panel Advisor)
Dr. Lance A. Leventhal	Emulative Systems (Report Editor)
Dr. Alex Marusak	Los Alamos National Lab.
Mr. David S. McFalls, II	Southwest Research Inst.
Dr. David Nitzan	SRI International
Mr. John C. Oldson	California Space Inst. (ARP Technical Manager)
Mr. Robert Pierce	SAIC
Dr. Frank Sinden	AT&T Bell Labs
Dr. L. Stark	Univ. California Berkeley
Dr. Martin O. Stern	California Space Inst.
Mr. David Stuart	MIT Space Systems Lab.
Dr. Randolph Ware	Univ. Colorado
Dr. Jack Wilson	Robot Systems International
Mr. Harry Wolbers	McDonnell Douglas

NASA and ATAC Liaison

These NASA personnel have assignments directly with the NASA Space Station Office or the Space Station Advanced Technology Advisory Committee (ATAC).

Dr. Victor Anselmo	NASA Headquarters
Mr. Aaron Cohen ATAC Chairman	NASA Johnson Space Center
Dr. Jon D. Erickson	NASA Johnson Space Center
Dr. Owen Garriott	NASA Johnson Space Center
Mr. Jon Haussler	NASA Marshall SFC
Mr. Daniel Herman Chief Engineer - Space Station Program	NASA Headquarters
Dr. Ron Larsen	NASA OAST
Dr. Henry Lum	NASA Ames Research Center
Dr. Jane Malin	NASA Johnson Space Center
Dr. Al Meintel	NASA Langley Research Center
Dr. Tom Pendleton	NASA Johnson Space Center
Mr. Robert Staehle	Jet Propulsion Lab.
Ms. Claire Wolfe	NASA Ames Research Center

Support Staff (California Space Institute)

Ms. Colleen Hauck
ARP Program Coordinator
Ms. Beth Di Julio
Ms. Marie Felthouse
Ms. Susan Hope
Mrs. Florence Kirchner
Ms. Teri Patterson

Contractor Participants

The firms involved in collateral studies of Space Station A&R supported attendance by key personnel at the major Panel meetings. Results of the contractor studies were distributed to the Panel.

Dr. Oscar Firschein	SRI International
Ms. Britta Gross	Hughes Aircraft
Mr. Ray Hallett	General Electric
Dr. Donald Kugath	General Electric
Mr. Hans Meissinger	TRW
Mr. Paul Meyer	Boeing
Mr. Richard Spencer	Martin Marietta Corp.
Ms. Amy Toussaint	Boeing
Mr. Donald Waltz	TRW
Mr. James T. Yonemoto	Hughes Aircraft

Study Reviewers, Advisors, Observers and Other Contributors

Dr. John A. Alic	Office of Technology Assessment
Mr. George Butler	McDonnell Douglas
Dr. Ronald D. Christman	Los Alamos National Lab
Ms. Paula Criswell	Emulative Systems (Tech. Editor)
Dr. J. Dray	Office of Technology Assessment
Dr. Grahme Fischer	Grumman Aerospace
Dr. Jack Foidl	TRW
Mr. Willis M. Hawkins	Lockheed Corp.
Dr. John Helly	The Aerospace Group
Dr. Ralph Kuiper	Lockheed
Dr. N. Metropolis	Los Alamos National Lab.
Dr. Al Meyers	SAIC
Dr. George Mueller	Santa Barbara, California
Dr. Ardell W. Nease	Rockwell International
Dr. Stewart Nozette	Univ. Texas, Austin (U.T. Coordinator)
Dr. S. H. Philipson	Jet Propulsion Lab.
Dr. Roy Radner	AT&T Bell Labs
Mr. M. Simon	General Dynamics Corp.
Dr. Paul Smolensky	Univ. California, San Diego
Dr. J. Solem	Los Alamos National Lab.
Dr. Harry Sonnemann	NASA Headquarters
Dr. Byron Tapley	Univ. of Texas, Austin
Dr. J. Torre-Bueno	American Innovation Inc.
Dr. R. Williamson	Office of Technology Assessment
Dr. Lofti Zadeh	Univ. of California, Berkeley

Foreword

The Transformational Frontier--A Historical Perspective

We are now passing through what appears to be the greatest evolutionary jump in human potential in history. In the last 40 years there have been revolutions in molecular biology, in jet airplane and rocket transport, in nuclear and solar power, in the management of the environment, in the weapons that have changed the face of war, and in the way that television is transforming our lives and cultural interactions around the world. Microelectronics and cybernetics are bringing us new powers in communications, data handling, learning and problem solving, and automation and robotics, and we are now seeing the beginnings of artificial intelligence. And, of course, in the last 25 years, the move into space has suddenly lifted human prospects into a new dimension.

In just a single human generation the achievements in each of these fields have expanded our powers by orders of magnitude--a transformation more rapid than any comparable jump in the history of life on Earth. If we represent this planet's 4 billion years of life by the 500 foot height of the Washington Monument, then the 4 million years of human existence are the the last six inches of the top block, and the 4000 years of recorded history are only a layer of paint on the block. But this jump we speak of, to a new kind of future in just a few decades, would be like a thin film of moisture atop the paint.

We may cross this hazardous moment in history to become a richer, healthier, more powerful and coordinated global species, expanding into space. It is a tremendous prospect. The uniting of so many powerful changes has created a take-off point in evolution--one whose future is almost impossible to predict.

Space as a Focus for Dramatic Change

What may be particularly significant in all these dramatic changes is how they contribute to finding ways of working and living in space. This new realm, so different from the one we evolved in, is one that we humans can begin to inhabit, with special problems and special benefits.

Space has no weather or friction, thus vast light structures undergo little stress and can be shaped or moved in new ways. For example, automatic factories, powered by sunlight, might operate continuously and unattended for years, doing integrated chemical processing of asteroidal or lunar materials. Dangerous experiments might be carried out more safely in space laboratories. The design and maintenance of balanced ecological systems for space habitats might be important not only for the occupation of space but also for learning about and preserving ecological systems on Earth.

Large satellite or Moon-based solar power stations, providing energy for space and perhaps for Earth, could transform our approach to space and create another evolutionary watershed, joining our already bustling satellite communications industry as a focus of profit. Eventually, lunar and other resources may even be "harvested" by self-replicating, autonomous machines, opening up vast new sources of wealth.

Development and Diversity

Such benefits from space are probably not achievable through either early and exaggerated enthusiasms or by too narrow a focus on one or two big programs. Rather, a careful approach combining vision, diversity, and practicality will work best.

The areas of greatest growth potential today are probably molecular genetics, artificial intelligence, and the development of space. (Note that these are at the frontiers, respectively, of the three basic levels of human organization, the gene, the brain, and the social organism.) Each of these has opened a vast and uncharted ocean of possibilities whose limits we cannot foresee. Space requires a heavier commitment of complex organization and long-range planning than either of the other two. Nevertheless, our approach to space, like our approach to genetics and artificial intelligence, should be as varied and imaginative as possible if we are to realize its full potential. In new growth fields of this kind, the essence is to explore the widest possible range of variations and combinations, to permit early and effective evaluation.

The history of technology has many examples of premature closures, and they have often been disastrous in the competitive world of business. Edison himself delayed the efficient distribution of electric power for a long time by his insistence on direct-current generators. In the 1960s, the great Mohole project for drilling completely through the earth's crust was finally replaced by the less expensive Glomar Challenger method of taking many smaller cores from the sea beds, and the findings revolutionized geology.

In the space program, such considerations would seem to favor further emphasis on automation and robotics to augment human-centered systems. Such tools can amplify greatly the powers of human beings and the different kinds of equipment and studies that can be controlled, monitored, and manipulated. These advanced tools are important in life support of humans and to assist human operators in emergencies, in diagnosis, and repairs. Automated equipment, telerobots for human-controlled manipulation at a distance, and general purpose robots can offer enormous flexibility, because they frequently require no more than a change of control program, when priorities change or new possibilities open. And advances in artificial intelligence can be incorporated into a prepared and well-developed program of automation and robotics (A&R), to provide new aids in pattern perception, expert-systems analysis, inference, and reasoning.

These are, of course, the reasons for the 1984 Congressional mandate that NASA vigorously pursue advancing A&R technologies. This report is a particularly valuable step in that direction. Only through as wide-ranging an exploration as possible, adapting to new findings and using the most advanced new technologies, can we be reasonably sure of avoiding the worst pitfalls, and of finding keys to the most rapid evolution. This is what A&R and advances in intelligence can add to the central national and human programs, to make a joint optimum of technical and human systems working together.

The Space Station will not be a place or a workshop so much as a *new tool*, a center for the makers of new tools, and a place to develop and demonstrate these tools. Space Stations, and eventually a space system consisting of many stations and components reaching out to the moon's orbit and beyond, will not only return direct benefits to us on Earth. They will also begin to open up another kind of destiny, developing a whole new dimension of human existence.

John Platt
Cambridge, Massachusetts

Chapter 1

EXECUTIVE SUMMARY

1.1 INTRODUCTION

PUBLIC LAW 98-371 OF THE 98th CONGRESS, DATED JULY 18, 1984, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION RESEARCH AND DEVELOPMENT, 98 STAT. 1227, RESEARCH AND PROGRAM MANAGEMENT REPORT states:

> "*Provided further*, that the Administrator shall establish an Advanced Technology Advisory Committee in conjunction with NASA's Space Station program and that the Committee shall prepare a report by April 1, 1985,
>
> *identifying specific space station systems which*
>
> *advance automation and robotics technologies,*
>
> *not in use in existing spacecraft, and*
>
> *that the development of such systems shall be estimated to cost no less than 10 per centum of the total space station costs.*" (emphasis added)

The United States Congress has taken a keen interest in how the National Aeronautics and Space Administration will manage the design, construction, operation, and evolution of the Space Station. This interest is driven by an awareness of the spectacular advances being made in electronics, computers, industrial automation, robotics, knowledge engineering, and related fields. Vital new industries and advances toward future possibilities are being created daily. The pace is accelerating, and there seem to be few acknowledged limits to these developments.

Congress became convinced that the Space Station program should not only incorporate these advances, but should also use this opportunity to stimulate national development. Demonstrations and applications of advanced technologies associated with the Space Station program will automatically receive high public and technical visibility.

The Committee on Appropriations (Department of Housing and Urban Development - Independent Agencies) recommended these responses by the National Aeronautics and Space Administration in Report 98-506 of the 98th Congress - 2nd Session (Calendar No. 967) to the challenges of advanced automation and robotics (page 65):

> "...the Senate bill requires...a NASA automation report. This report and the *ongoing NASA-sponsored automation study* are expected to be completed no later than April 1, 1985.
>
> The Committee also expects the contractors (i.e., Space Station Contractors) to devote a significant portion of their effort pursuing the study of automation and robotics technologies identified in the mandated report *with the objective of advancing the state of the art in these technologies and increasing their terrestrial application.*
>
> The Committee acknowledges the need to pursue a manned space station, however, the Committee believes that NASA needs to pursue the areas of automation and robotics more vigorously. Consequently, the bill language is intended to assure that *such advanced technologies are indeed made an integral part of the planning and development for a manned space station.*" (emphasis added)

1.2 FINDINGS OF THE PANEL

The Automation and Robotics Panel (ARP) concludes that Congress was correct in its initial judgement: *NASA can indeed significantly improve the effectiveness and reduce the cost of Space Station operations through the use of advanced automation and robotics. Capabilities in A&R will be accelerated, leading to broad national benefits.*

All major systems and most subsystems of the Space Station can be advanced over implementations in existing spacecraft (including ground support). Capabilities and efficiencies will expand if the program is designed, *from the beginning*, to accept and absorb future advances in automation and robotics. By establishing a strong technical base early, the Space Station will be able to accomplish an ever wider range of missions, and do them better and at lower cost than if only limited use is made of advancing technologies.

NASA can be challenged to move from Earth-based, human-intensive control of space operations toward highly mechanized systems located in and largely controlled from space. As they become available, advanced automation and robotics can be steadily incorporated into the Space Station to make it capable of autonomous operations for increasing periods. Transfer of control from ground to space can result in economies of operation.

Making this come true will require that *NASA make the necessary major investments to advance the technology base.* This can be accomplished through a complementary, multileveled approach. NASA can *lead* in the development of space-unique technologies, the Agency can *leverage* terrestrial technologies adaptable to the space environment, and it can learn how to *exploit* off-the-shelf technologies by providing the proper environments in space. Careful analysis must be used to determine the correct level for each development.

This is an important issue, because NASA cannot lead in all areas of technology. The Space Station program must, of course, utilize many components designed exclusively for space; special techniques and hardware will require a vigorous technology advancement and demonstration program continuously pushing the state of the art. However, in many domains the program can simply adapt techniques developed for terrestrial applications. Commercial organizations on Earth, such as communications companies, large chemical refineries, and computer centers at national laboratories, are currently more sophisticated in many areas of technology than is NASA. The more the Station draws on terrestrially developed technology and procedures, the faster the nation's presence will expand profitably into space.

Automation and Robotics (A&R) applies to many other activities of NASA besides the Space Station. Extensive interaction should be fostered between the Office of Space Science and Applications (OSSA) and A&R. Future explorations of the moon, asteroids and other bodies might lead to permanent automated centers near or on the object being studied. These centers could be upgraded regularly via small packets on relatively inexpensive flights from low-Earth orbit. A permanent center could support wide-ranging local exploration via probes, reusable orbital transfer vehicles, or *in-situ* propellant production. In all of this, OSSA could make efficient use of advances made elsewhere, especially in the Space Station program. Closer to home, advanced A&R can provide terrestrial scientists with far greater access to orbital facilities, can decrease unit costs, and permit more extensive experiments.

The Office of Aeronautics and Space Technology (OAST) is also active in automation, e.g., in developing highly reliable electronic controls for aircraft. The Office of Space Flight, using the Space Transportation System operations, or components on board the shuttle in space, can advance Space Station planning with efforts in A&R.

Most important, humans can progress to increasingly higher-level tasks as automated systems take over routine jobs. Such achievements require fundamental knowledge of how to organize exceedingly complex, even somewhat "self-aware" systems. NASA Space Station programs can demonstrate complex service functions in "smart" computer systems or extend the electronic reach of humans.

The Space Station can demonstrate technologies that soon will have new applications on Earth. These technologies will be used, for example, in non-invasive monitors of human health, and in helping the elderly or handicapped. Demonstration of new capabilities in the unforgiving environment of space will educate a wide audience. NASA has a record of achieving progressively more demanding goals in full public view. ARP concludes that the Space Station program can be related even more intimately to the mainstreams of American life and technology than were past space activities.

At the same time, NASA can learn to take advantage in space of the increasingly complex devices now becoming part of everyday life.

The entire Agency, and certainly the Space Station Program Office, could take advantage of currently available techniques in office and industrial automation. For instance, the Space Station request for proposals states specifically that engineering design data must be submitted in electronic (computer usable) form. Far greater advances can be anticipated as we learn to "electronically" conduct complex activities. NASA's openness, the nature of its missions and the technological interests of its personnel all contribute to its suitability for demonstrating advanced automation in service activities.

A permanent Space Station program can expedite the smooth growth of our presence and capabilities from Earth to space, also supporting people whose efforts are directed to non-Space Station tasks. As a wider spectrum of people and tasks are moved out to orbit, it will become clear that the Space Station program is not just an end in itself. There will be benefits far beyond the initial concept of living quarters and a workshop in low-Earth orbit.

The "Space Station program" will never mean the same thing to all people. It should be considered as part of a continuum in time, space, and society. It is building and evolving the first major tools for people to use for creative work beyond the Earth. To achieve the program's varied ends, the Automation and Robotics Panel offers its recommendations in the next section, based on the findings of its study.

1.3 RECOMMENDATIONS

The following compilation of the Panel's major recommendations is supported and expanded by accompanying exhibits and discussion.

Design the IOC Space Station (Initial Operational Capability) to accommodate major evolution and growth in its use of Automation and Robotics

Recommendations

1. NASA's goal should be to achieve, in stages, a very high level of Space Station automation by the year 2010. This level will
    a) greatly enhance effectiveness and productivity, and reduce operational costs.
    b) allow astronauts to perform duties primarily involving decision-making, supervision, and creative investigation.
2. The IOC Space Station should be designed to emphasize its capability to grow and evolve, accepting new advances with minimum retrofit. This will allow incorporation of the best and highest level of automation available at a given time, at minimum cost.

    This emphasis, established from the beginning, will be particularly important in accepting the technologies and concepts listed in Exhibit A.

3. Phase B contractors should be graded on how well they achieve Recommendation 2 (above). Selection of contractors for phases C and D should be based substantially on how well they address the goals in Recommendation 2.
4. From the beginning, NASA should search actively for and allow for breakthroughs that might surpass even current predictions of what is likely by the year 2010.

Exhibit A

Technologies and Concepts Important to Growth and Evolution of the Space Station

- Natural and efficient man/machine interfaces (e.g., voice and speech comprehension, heads-up displays, supervisory control of robots).
- Robot accommodations (e.g., standard fastenings, bar codes).
- Advanced robot capabilities (e.g., perception, manipulation, judgment, mobility).
- Standard high capacity, redundant, fault-tolerant internal and external communications networks.
- Modularity concepts that facilitate system evolution.
- Standard computer languages.
- Problem-oriented user languages.
- Comprehensive simulation for operational planning and decision making (including parts and system status, scenario testing).
- Integrated computer aided engineering and some on-site fabrication capability.
- Systems that are tolerant and protective of personnel.
- Expert systems and dynamic databases conducive to growth.
- Continuously improved computer systems, including parallel processing, and high speed circuitry.
- Methods for identifying, evaluating, projecting, and displaying effects of rapidly evolving technologies.
- Self evaluating, self repairing life-support and utilities systems with reduced dependence on Earth provisioning.
- Operational policy that utilizes astronauts in increasingly higher levels of creative activity, liberating them from routine functions.

Implement advances in Automation and Robotics throughout the Initial Operational Capability (IOC) Space Station

Recommendations

5. IOC should feature the attributes in Exhibit B, especially including
    - Selected designs featuring modularity, reserve capacity, flexibility, and standard protocols.
    - Excess information storage and channel capacity.
    - Suitable environments for movement, operation, and recognition by robots.
6. Automation and robotics milestones should be demonstrated before IOC. Exhibit C shows suggested pre-IOC demonstrations and milestones along a hypothetical time line.
7. Control should be shifted as much as possible from Earth to a space-based operations center to reduce costs through automation while increasing station autonomy.

Exhibit B

Features of the IOC

- New ways of promoting the use of state-of-the-art A&R hardware to allow use of evolutionary design of computer and robotics systems.
- A flexible Earth-based computing/network test-bed for developing initial and later generation space station information management systems.
- Selected designs featuring modularity, reserve capacity, flexibility, and standard protocols.
- Initial devices and structures that allow for ease of operation, recognition, and movement by robots; this includes standardized markings (e.g., bar codes), color codes, connectors and other fastenings, and computer/network interfaces.
- Initial use of expert systems for selected tasks such as utilities analysis, fault isolation, environmental monitoring, information retrieval, and astronaut briefing.
- Provisions for obtaining and representing knowledge derived from experience for use in later, more competent expert systems.
- An initial network design and hierarchical computing system that allows for increasing decentralization.
- Selected initial and increasing use of autonomous robots.
- Deliberate accommodation, testing, and use of equipment and procedures developed in terrestrial applications for non-critical functions.

Exhibit C

Suggested pre-IOC A&R Demonstrations and Milestones*

	Near-Term: To 1988		Mid-Term: 1989 to 1992 (IOC)	
General		Flight-test some common "off-the-shelf" hardware (e.g., *memory drives*) to develop simpler flight qualification standards	Demonstrate dexterous end effectors and tools	
Robot Hardware	Terrestrial demos in simulated space environment - Semi-autonomous Space Station assembly - Automated inspection - Autonomous "go-fer"	Begin flight demos in shuttle Complete telerobot compatibility standards for Space Station design	Continue flight of terrestrially demonstrated hardware Demonstrate techniques for in-space parts adaptation/fabrication	"Scars" for hardware implementations after IOC
Sensors	Develop sensors & low level perception systems to support specific requirements of Space Station		Develop special-purpose hardware for sensory data processing	
Controls and Man/Machine Interfaces	Identify A&R human factors concerns	Develop and demonstrate force feedback for Shuttle Remote Manipulator System	Demonstrate robotic control systems pertinent to space environment - Micro-g manipulation - Flexible arms - Execution monitoring with real-time simulation	Demonstrate limited speech control operator interface Demonstrate multi-arm telerobots and robots for internal & EVA applications

Artificial Intelligence and Knowledge Engineering	Lab demos of space applicable early expert systems Utilities monitor Life Support System monitor Data storage/access Astronaut briefing	Accommodate in space and on the ground CAD databases, describing and integrating Station components from all contractors	Flight demos of early expert systems Demonstrate flexible dynamic simulation using CAD database	Demonstrate[†] expert system applications to - Crew activity planning - Communications monitoring -Fault isolation

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[*] Discussed in Section 2.6

[†] Development should start immediately.

Apply Automation and Robotics (A&R) funds to advance the technology base, meeting Space Station needs

Recommendations

8. Resources for research and demonstrations must be carefully allocated for technology advancement in

   a) areas in which NASA must *lead*.

   b) areas in which NASA must interact with and vigorously *leverage* outside developments.

   c) areas in which NASA should *exploit* progress made by industry and other outside communities, devoting in-house effort primarily to intelligent purchase and space-qualification of off-the-shelf technologies.

   A proposed list of such technologies is presented in Exhibit D. Exhibit E depicts an approximate initial distribution of suggested funding. More discussion of these issues is given in Section 1.4 and Chapters 3 and 4.

9. The Panel recommends that a long-range technology advancement and demonstration program (distinct from engineering development and deployment activities) of significant size be funded to ensure that *needed* A&R technologies are developed for both the IOC and beyond.

   a) **A baseline program of technology advancement and demonstration should reach approximately $190M annual funding well before IOC, e.g., by 1990. A minimally effective program serving some of the A&R technology needs of the Space Station must reach approximately $100M annual funding by 1990.**

   b) **Approximately 85% of this budget should be applied to the technology advancement program, and 15% to timely demonstrations of new capabilities emerging from that program.**

   Exhibit F summarizes the Panel's recommendation for program funding to best enhance Space Station capabilities both at IOC and afterwards.

10. **NASA must sustain a continuous, aggressive A&R technology program at all phases, considered as a national goal, but targeted at the needs of both pre- and post-IOC, regardless of any delay in the IOC program itself, or other disruption in funding.**

Exhibit D

Automation and Robotics Technology Advancement Program

Class	Man Machine-Robotics	Information Management	Communication & Mechanical Infrastructure
NASA must *lead*[*]	Space Manipulators Materials Handling Technologies Robot Mobility in Space Man Machine Interfaces	Expert System Mission & Payload Control, Planning & Directing "Smart" Simulations Fault-Tolerant, Reliable Software Tools CAE Standards Software Language Standards Automation Design for Integrating Technology	Lightweight Structure & Assembly Spare Parts & Repair Technology Fluids Transfer Technologies
NASA applies *leverage*	Robot Sensors Integration Reconfigurable & Repairable Robots High-Level Robot Programming Language	Space-Related Custom Hardware Communications Networks Distributed Large-Scale Databases CAD-Directed Programming Knowledge-Based System Development Sensing Algorithms Real-Time Systems Facility "Seed" Funding	New Fabrication Technologies
NASA can *exploit* (examples)	Terrestrial Robots and Manipulators Lightweight Motors	Computer Architecture Chip Technologies Speech Technologies	Local Area Networking Display Technologies High Bandwith Technologies Communication Technologies

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[*] Programs specified for "NASA must *lead*" logically contain technologies in which "NASA applies *leverage*" and "NASA can *exploit*." For clarity, program designations were placed only at the highest level; with time, programs may change level.

Exhibit E

Automation and Robotics Technology Program Cost Summary*

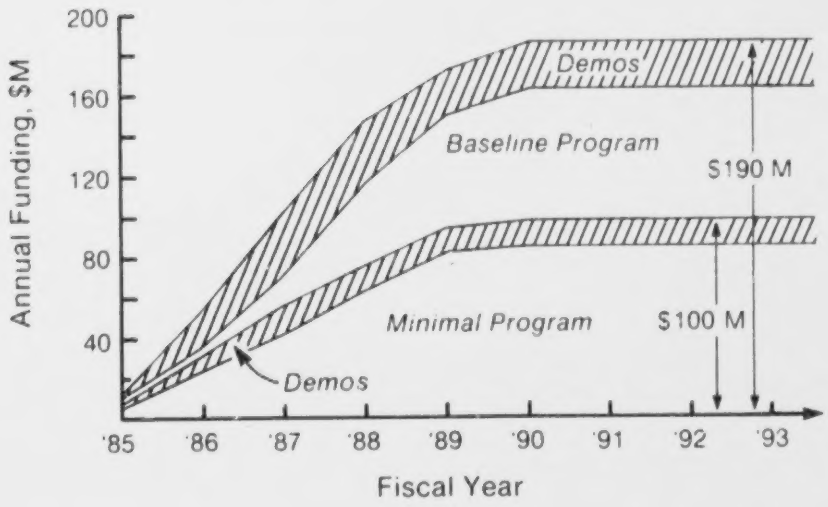
	Annual Funding Levels ($M/yr)	
	Baseline Program	
	Research	*Demos*
NASA Leads:		
Man/Machine-Robotics	51	10
Information Management	26	4
NASA Applies Leverage:		
Man/Machine-Robotics	25	4
Information Management	31	7
NASA Exploits (Buys):		
Man/Machine-Robotics	< 1	< 1
Information Management	4	< 1
Infrastructure Technical Adjustment†	23	5
Program Totals	160	30
Combined Elements	190	

* After 1990 on Exhibit F

† "Man/Machine-Robotics" elements are addressed in Chapter 3. "Information Management" applications are covered in Chapter 4. "Infrastructure Technology Adjustment" is a category of expenditure dealing with *integration* of various technologies into overall station design. Part of the latter can be thought of as *exploiting* and space-qualifying Earth-derived technologies.

Exhibit F

A&R Technology Advancement Program Funding Guidelines



Establish management structures that ensure rapid, ongoing advancement of Automation and Robotics (A&R)

Recommendations

11. Establish management structures in NASA to ensure that
    a) the needed A&R technology advancements occur unimpeded by Space Station operational or budgetary problems.
    b) there is a strong linkage between the technology advancement program and Space Station A&R implementation activities.
    c) the goals for Space Station A&R technology advancement reflect a consideration of broader applications (including terrestrial).
    d) the A&R technology advancement and implementation activities have visibility and accountability to the highest levels of NASA and to Congress.

12. Without presuming to recommend a specific organizational structure, the Panel further suggests strongly that NASA accomplish Recommendation 11 by providing
    a) an organization, managed outside the Office of Space Station, to lead the A&R technology advancement activity.
    b) the A&R technology advancement activity with a line item at no lower than a first level breakout of an Associate Administrator's budget.
    c) a second organization, administered within the Office of Space Station, charged with promoting smooth flow of capabilities from the A&R advancement activity to Space Station operation, and with conducting required prototyping and testing activities.

13. Create an external review panel consisting of experts from universities, industry, and government to
    a) conduct in-depth review of NASA A&R activities.
    b) advise NASA.
    c) present annual reports to Congress.

Promote interactions among and benefits to national communities

Recommendations

14. Establish mechanisms for vigorous interactions among the national research and development communities (e.g., through joint participations in critical technology development programs, national conferences, interactive networks, and data exchanges). Keep abreast of A&R advances made by, for instance, industry, DARPA, NBS, and foreign groups.

15. Actively promote dissemination of NASA advances in automation and robotics for the general benefit of the nation by employing a vigorous NASA program of technology exchange. Facilitate both Earth and space-based applications.

16. Use advanced automation and robotics to increase the capabilities and improve the efficiency of NASA's operations, both space- and ground-based. Consider these activities as a focus for learning more about the management of modern, complex programs. This recommendation applies throughout the Agency, not only to the Space Station.

17. Establish incentive schemes to encourage new participants to become involved in NASA programs.

1.4 DEVELOPING THE TECHNOLOGY BASE

How can we be sure to develop the technology base for advanced automation and robotics that the Space Station program will need? The process involves four steps:

Step 1 - Provide the advancing technology base.

Step 2 - Conduct early demonstrations (ground and flight) of key new capabilities.

Step 3 - Develop and test prototypes.

Step 4 - Achieve operational implementation.

It is clear that the scope of effort at each succeeding step narrows, beginning from a broad range of key technologies in the applied technology program and proceeding to specific systems at the implementation phase. The ARP recommendations primarily encompass Steps 1 and 2. These stages in the total A&R development process will need to draw sharply upon NASA centers, university laboratories, and industrial research programs.

In addressing the budget required to provide a solid technical base for Space Station A&R, the ARP focused on the period between now and IOC, i.e., 1985-92. It is equally important, however, that funding for this program, in place at IOC, be maintained in subsequent years to continue to advance the technology base for evolving Space Station needs.

To achieve the objectives summarized in Section 1.3, the Panel makes the following specific recommendations concerning funding:

a) A solid baseline program of both technology advancement and key demonstrations would need to reach an annual funding level of $190M well before IOC, e.g., by 1990.

b) A minimally effective program to support the A&R technology needs of the Space Station, before and after IOC, must reach $100M by 1990.

c) If the baseline program cannot be supported, ARP has developed fallback priorities in the recommended technology advancement program. This will maintain well balanced efforts in the most critical technology areas even in the event of constrained funding.

Representative annual funding in 1990 for the *baseline* and *minimal* programs required to support advancement and demonstration of key automation and robotics technologies is summarized in Exhibits E and F. Details are given in Chapter 3 (Exhibit G) and Chapter 4 (Exhibit H).

ARP members who manage private and government A&R programs estimated the professional labor (man-years per year) required for the *baseline* and *minimal* programs. The various programs will require different labor skills and development support. These factors were accounted for in estimating the annual program costs in Exhibits E and F. Demonstrations were costed separately. Then the order of fallback from *baseline* to *minimal* program was specified.

Clearly, NASA cannot, and should not try (as it did in the mid-1960s) to lead in nearly every advanced technology. Major efforts to develop NASA in-house and contractor expertise should focus on particular areas, especially those areas of automation and robotics in which Space Station needs simply will not be met without intensive NASA-supported efforts. In these fields, NASA must *lead*.

In many areas, vigorous developments by industry, defense and university communities will advance technologies. NASA can *leverage* these developments and apply them in space. Carefully chosen interventions could have dramatic effects. To do this, NASA must have high level, in-house expertise in these selected areas.

Finally, there will be many areas in which NASA should *exploit* available technology. These are fields in which industry is already forging far ahead, developing and mass-producing rugged, sophisticated hardware and systems that might function well in a space environment. NASA must establish enough in-house expertise in these areas to evaluate off-the-shelf technologies, develop more efficient space-qualification standards, and make these systems available to users in the Space Station program. In areas that NASA must generally *lead*, NASA should also *leverage* and *exploit* component systems available from other sources. With continuing imaginative approaches, NASA and its contractors can maximize the range of new technologies that do not have to go through Steps 2 and 3 or even more than a minimal check at Step 1.

Exhibit D presents distribution of proposed technology efforts along these lines of emphasis. They are broken down among Man/Machine-Robotics applications, Information Management applications, and Infrastructure Technologies specific to Space Station. Man/Machine-Robotics applications are the topic of Chapter 3, Robotic Systems. Information Management applications are covered in Chapter 4, Computer Science and Knowledge Engineering. Infrastructure Technologies addresses Space Station unique applications, each of which integrates several of the technologies included in both Chapters 3 and 4. While discussion of these applications is premature, given the current embryonic stage of the Space Station design, they must be identified as part of the total research program.

The *government procurement cycle* is now itself a serious impediment to Space Station use of advanced technology. It is complex, difficult, slow, and especially troublesome for prototype devices and development contracts. Smaller companies, often the leaders in automation and robotics, frequently decline to enter the process at all. In fast-moving areas, the procurement cycle can take longer than a technology's generation time, and itself guarantees obsolescence in the installed hardware.

Some parts of the government use simpler, more rapid procedures. Given the congressional view (which we share) that this technology is a matter of national urgency, there is a strong case for authorizing NASA to use such procedures for certain types of Space Station technologies.

It is essential that NASA sustain an aggressive A&R technology program at all phases, targeted at needs both before and after IOC. In the event of delays in IOC, automation and robotics will actually *increase* in importance, representing probably the best avenues toward recovery of lost time and opportunities. This important effort is vital to the success of the Space Station and the consequent A&R benefits to our nation. Disruptions in funding must not sidetrack NASA from a continuing pursuit of the stated A&R program objectives.

1.5 ENSURING ADVANCEMENT AND IMPLEMENTATION

The previous section has pointed out that to achieve the A&R implementation necessary to make most effective use of the Space Station, there must be several levels of substantial A&R activity within NASA. Two fundamental characteristics distinguish these levels: the degree of innovative risk involved, and the time frame in which the work is conducted. There is large variation in these characteristics as one progresses through the four stages identified above. At Step 1, the technological risk is fairly high; only a fraction of the approaches investigated will ultimately lead to operational devices. The time frame can be very long, 10 to 20 years in many cases; technology advancement work begun now will be principally directed toward post-IOC implementation. On the other hand, activities at Step 4 have high public visibility, must involve low risk, and must meet rigid time schedules.

The risk and time-frame characteristics of the activities could lead to strongly conflicting goals at various organizational levels within NASA. Experience in many different programs has shown that long-range advancement is often compromised by short-term solutions to immediate problems. Conversely, persons dedicated to technology advancement propose ideas but often have no means of reducing them to practice.

Recommendation 11 sets forth operating principles designed to resolve such conflicts to the Space Station's best advantage. The Panel recognizes there are a number of possible management structures for accomplishing the desired long-term goals. The ARP feels that managers required to deal with these conflicting goals must be accountable to higher authorities. This concept is represented in Recommendation 12, the

Panel's preferred characterization of the mechanism for implementing Recommendation 11.

A separate A&R technology advancement organization (see Recommendation 12a) will focus A&R activities, allow implementation of long-range planning, and introduce new ideas for automation and robotics in space. Separation of this organization from the Office of Space Station reduces the possibility that A&R advancement funds will be used to cover unexpected Space Station delays or costs. It will also provide the freedom to pursue new ideas outside the daily pressures of implementation details and deadlines. The appearance of the A&R technology advancement budget as a line item (see Recommendation 12b) at a high level will provide visibility and accountability for the program. This is consistent with the level at which the activity was initiated, and also provides a degree of security against the use of its budget for other purposes.

The establishment of a second organization, this one within the Office of Space Station, will promote the smooth flow of new capabilities from demonstrations to operational status. This organization would have principal responsibility for Step 3, described above, but would work closely with the A&R technology advancement activity to perform the concept demonstrations of Step 2. It should have a major, but not dominant, voice in setting goals for and monitoring the A&R technology advancement activity. It should also select, develop, and promote the best ideas for use in the Space Station.

Finally, the ARP recommends that an external review panel be established to periodically conduct in-depth reviews and make recommendations to both NASA and Congress. It can help NASA maintain a top quality focused A&R program by promoting awareness of external A&R activities, and can be a strong voice of advocacy to Congress on A&R matters.

1.6 ORGANIZATION OF THE REPORT

The chapters are organized as follows:

Chapter 2 (Designing for Growth in Automation) suggests methods for promoting continual growth in Space Station automation and robotics. It emphasizes IOC design criteria that will allow for ever-increasing levels of automation. These include

- Providing abundant onboard computing power, storage facilities, and databases.
- Introducing expert systems early and continually adding to their functions.
- Identifying routine functions and planning for their gradual automation.
- Allowing for onboard control and simulation of Space Station processes through the use of CAD/CAM methods.
- Use of standard connections, fittings, and markings that automated systems can utilize or recognize.
- Allowing for robot mobility and capabilities in the design of distribution networks, structures, assembly methods, markings, and by other means.
- Separating upgradable functions into replaceable modules, micro-modules, or boxes.
- Developing a replaceable automation module that includes robots and facilities for controlling both them and other automated systems.

This chapter also summarizes the required technology advancement programs and presents example pre-IOC technology demonstration projects.

Chapter 3 (Robotics) describes the required technology advancement in robotics. It explains the need for improved human-machine interfaces, manipulators (teleoperators) and sensors, and their combination with Earth-developed robot technology into hybrid systems. It presents typical applications and scenarios in the areas of

- Assembly and construction.
- Materials handling.
- Satellite servicing and manipulation.
- Inspection and monitoring.
- Repair.
- Manufacturing.
- Experiment control.

Major research subjects in this area include end effectors and mechanization, control systems, telepresence and human factors, robot perception, manipulation in zero-gravity, operation planning using CAD/CAM databases, and robot self-diagnosis and repair.

Chapter 4 (Computer Science and Knowledge Engineering) presents the needed research base in computer science, artificial intelligence, and applied mathematics. It emphasizes

- The need for a hierarchical computer network that allows for both central control and distributed processing.
- Introduction of specialized machines for both signal and symbolic processing.
- The importance of developing adequate database standards and methods for accessing and transporting data.
- The need for improving tools and facilities for designing, developing, testing, and maintaining expert systems.
- Significant pre-IOC demonstration projects for expert systems.

It describes methods for developing these systems in a way that is largely machine-independent, distributed, and based on standard languages, interfaces, and communications techniques.

Chapter 5 (Interactions with Private and Government Sectors) explains the effects of Space Station automation and robotics on both private and governmental institutions. It describes ways to

- Obtain effective contributions from private industry, laboratories, and academia.
- Use private sector developments in the Space Station.
- Promote use of the Station by industry, other U.S. government agencies, universities and research institutions, and foreign governments.
- Use Station automation and robotics technology advancement externally.

Chapter 6 (Broader Opportunities) explains why the Station will be a continuum in time, space and society. Since it will be in operation for many years and will be used in a variety of projects, autonomy, flexibility, capacity for growth, and ease of use and operation will all be key factors. Extensive implementation of automation and robotics can help

- Provide autonomous operation without extensive ground support, and allow much better recycling and leveraged use of materials.
- Serve deep-space missions and lunar activities, and open opportunities to use new resources.
- Maintain basic Space Station core functions despite crew changes.
- Make space accessible to a much wider range of people.
- Help automate NASA operations and demonstrate advanced service automation to the nation.
- Provide the basic ability to take advantage of major technological breakthroughs.

Chapter 7 (Advancement and Implementation) contains organizational recommendations for meeting Congressional goals for Space Station automation and robotics. It emphasizes the need for

- An independent entity in NASA with responsibility for automation and robotics technology advancement and transfer.
- An organization within the Office of Space Station that ensures the actual implementation of automation and robotics systems.
- An external review panel of experts who establish goals and priorities and review progress.

1.7 CONCLUSION

On a daily basis, space is becoming increasingly intertwined with the life of every American. The Space Station is a major step toward the creation of a set of tools that will permanently sustain people beyond Earth and allow them to work in bold new ways for the benefit of all.

The space program is growing dramatically, both technologically and in the *scale* with which we do things. For example (with the exception of Skylab), the total mass of all manned capsules and landers previously flown by the United States is less than seven shuttles could carry to orbit. The Space Station will continue this revolution in scale.

Rapid physical growth is being increasingly augmented by developments in electronics. Advances in communications, computers, and robotics can increasingly leverage the capabilities of people, especially in space.

The Space Station can provide a permanent presence and sustain rapid growth off Earth during a short period in which America effectively has no major competitors. A central purpose of this report is to help design a program that will enable the nation to take advantage of this special time in history. Automation and robotics, applied vigorously now, can deeply map our human endeavors into near space, onto the moon, and beyond.

Chapter 2

DESIGNING FOR GROWTH IN AUTOMATION

2.0 SUMMARY

This chapter explains how achievement of a high level of automation throughout the Space Station's history will require an early, consistent design commitment. Robots and expert systems must be introduced as early as possible and their functions must be expanded continuously. Most important, Initial Operational Capability (IOC) design must *foster* increased automation by providing an appropriate infrastructure. Upgradable systems must be separated into replaceable units or modules to promote a regular schedule of changes, and designers must always look for ways to automate functions.

The ultimate goal should be for crew members to operate exclusively in a supervisory capacity or do advanced work.

To promote ever-increasing levels of automation, Station design should

- Consider robot mobility and the capabilities of robots and expert systems in planning internal and external structures, distribution networks, and assembly methods.
- Provide ample onboard computing power and storage, databases, control functions, and simulation facilities.
- Use standard fastenings, fittings, labels, color codes, computer network interfaces, and markings that automated systems can utilize or recognize.
- Provide a distributed network of sensors from which automated systems can derive data.
- Use standard but extensible formats for data communications.
- Provide reserve bandwidth in cabling and networking.
- Distribute computing power to promote expansion and avoid single points of failure or capacity over utilization.
- Include a comprehensive design database, covering geometry, connections, mechanisms, and equipment.

Just as important as the initial design philosophy is a commitment to a dedicated, sustained NASA program for *advancing* specific areas of *fundamental technology* in automation and robotics (A&R). This is essential if we are ever to realize the great cost savings and productivity improvements that Space Station automation could produce. While the advancement program must interact vigorously and systematically with the Office of Space Station (OSS), its resources must be dedicated to technology advancement and protected by budget structure and by a separate reporting line.

2.1 INTRODUCTION

Attention and resources must be devoted to *technology advancement* in automation and robotics. Then (and only then) will America's Space Station (*circa* 2000-2010) provide its services at high efficiency and low cost, at levels difficult to imagine today.

The Congressional mandate is a crucial and farsighted first initiative. But two more steps are equally essential in our view, or the promise will go unfulfilled and the Space Station of 2010 will remain a costly, labor-intensive operation. These two steps are to

1. ***Require consideration of future automation in IOC Space Station designs.***
   NASA should require that designs for the IOC Space Station, *circa* 1992, (employing only a current state-of-the-art level of automation) demonstrate a capability to grow, in every aspect and at minimum retrofit cost, to the level of automation *possible* by the year 2010.

2. *Provide dedicated management of technology development resources in automation and robotics.*

   NASA should establish a separate organization to advance automation and robotics technology.[*] This organization should manage expenditure of all funding that the Act earmarks for development in this area. Systematic, vigorous interaction with the Office of Space Station should be required. For example, a high Space Station program official might be part of an A&R technology steering committee.

It is essential that resources be fully dedicated to *fundamental technology advancement*, to develop leverage for the future Space Station.

2.1.1 Designing for Higher Levels of Automation

The first step is that the IOC Space Station (the operation of which will be primarily a manual activity) must be designed to evolve and accept increasing levels of automation and autonomy.

It is clear that to achieve IOC, in say, 1992, the initial Space Station design will need to be frozen only a few years from now, with a level of automation not much higher than today's state of the art. The great benefits of cost-saving will come later, as automation emerges from the R&D community and from large commercial development enterprises. But the Space Station will benefit only if the IOC has the infrastructure to accept new developments. The National Research Council (NRC 1985) has examined the challenges to development of the Space Station, illustrating some of these issues.

The proposed modular nature of the Space Station meshes readily with this infrastructure, but much thought, commitment, and a design-review discipline is necessary to make it a reality.

We must first try to imagine the level and form of automation in 2010. This is the basis for specifying the details of design for growth of the IOC Space Station. It is the major task of this chapter.

Section 2.2 describes the benefits of a highly automated Space Station, with astronauts in a high-level management role. It outlines how the nature of the man-machine team could evolve during the next three decades.

Section 2.3 examines the kinds of capabilities that could be operational by 2010 if the proper fundamental technology advancement work begins in 1985.

Section 2.4 suggests a first compilation of 1992 IOC design features that would help ensure that the Space Station can grow continually and smoothly toward the level of automation described in sections 2.2 and 2.3. Without such planning, prohibitively expensive retrofitting would be necessary.

Section 2.5 outlines specific areas requiring technology advancement efforts to provide the base for developing the Space Station.

2.1.2 Assuring Development of New Technology

The automation and robotics effort is designed primarily to benefit the Space Station. However, there are important reasons for maintaining a degree of separation between them. We believe that NASA must establish a dedicated organizational unit to manage the funding of *fundamental* automation and robotics technology for the Space Station. This funding could exert significant leverage on the nation's technology development community--but only if it is dedicated to *advancing* pivotal basic technology. A fraction could be used for selected in-house work. The bulk would fund industrial and university laboratories.

The technology advancement program should, of course, be coupled closely with the long-range needs of the Space Station. One way of accomplishing this might be a joint steering committee in which a high Space Station program official would play an important role. Strong working-level interactions should also be structured carefully.

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[*] There should also be an organization dedicated to providing specific automation subsystems for implementation and operational deployment in the Space Station. See Chapter 7 for further details on recommendations regarding these two A&R organizations.

The goals should always be useful devices and systems, not pure research. There is a danger at the opposite "applied" extreme, however. If the automation and robotics funds were allocated at the discretion of and by the OSS, they would surely (and with understandable motivation) be used to help meet pressing IOC requirements–albeit in the name of automation. This would hamper fundamental advances in automation, and the future Space Station would have little more automation than today's state of the art allows--far short of what it could have. Thus we believe that independence from direct OSS management is critical. Chapter 7 covers this topic in more detail.

2.2 THE IMPORTANCE OF DESIGNING FOR FUTURE HIGH AUTOMATION

In the first 25 years of the Space Age, we have seen rapid evolution from the earliest simple, small orbital payloads into large, highly sophisticated manned and automated space facilities. Continuing problems in the design and development of these facilities are the long lead times required, the lengthy lifetime of payload operations themselves, and the added expense and risk of last minute attempts to include the latest technological innovations. As a result, space payloads typically use technology some 10 years behind corresponding ground facilities. For the Space Station, which is intended for permanent habitation for, say, 10 or 20 years, beginning in about 1992, we must find a better way.

Concurrent with, and as a result of our rapidly advancing sophistication and capabilities in communications, electronics, and automation, the role of the space-flight crew member has also changed. Mercury and Gemini involved relatively simple tasks and used almost total onboard manual control. In Apollo and Skylab, substantially greater reliance on computer technology was possible, and a much closer interaction with ground investigators enhanced the value of scientific data return. Currently, with the shuttle and Spacelab, the degree of interaction has become quite high, with ground and space investigators operating essentially as a single team. Where appropriate, research team members themselves fly in space to operate the hardware they helped design.

The roles of the flight crew have also become more specialized, as their numbers have increased from a few to 7 or 8 in the shuttle. The majority of the crew members now devote most of their time to payload related activity. The role of the *payload specialist* includes control of teleoperators (the remote manipulator system is an early device), deployment of satellites or platforms, set-up of experiments for (semi-) automatic operation, evaluation of data quality to assure satisfactory performance, participation as test subjects, repair and maintenance of space hardware, interpretation of experiment performance, and selection of operating modes based upon real-time evaluation of the results.

These trends of payload complexity will grow even more pronounced in the developing Space Station. A major challenge in Space Station design will be to provide for many modes of operation. Crew will operate either autonomously or in concert with ground-based colleagues. The combined team will use the latest technological innovations such as nearly full-time, wide-bandwidth downlink data, television, and voice coverage for *payload-related* activities. The earliest Space Station designs will have to allow expansion and modernization of communications and control. Likewise, as teleoperators become more expert and proficient, the Space Station must be able to support their introduction and increasing use.

In contrast to the astronaut involvement in payload activities, the routine and repetitive ***housekeeping*** tasks should be taken over totally by onboard computer-automated control. Thus, by 2010, humans should be operating purely in a high-level, payload-oriented supervisory role.

As time passes, the jobs done by the human crew will change. One example might be materials processing or space industrial activities. Initial payloads will be human operated, but later systems will feature high levels of automation, freeing people to work on the next technological cutting edge. Substantial economies will ensue from automated support systems that allow control over both normal operations and extreme conditions. For example, life support systems that recycle vital elements will sharply decrease the cost of space operations by increasing autonomy from Earth re-supply. However, the control of such systems will be more complex and require more automation than does the control of more traditional systems.

The following chapters of this report describe the capabilities we believe will be required up to the year 2010. The Space Station's designers must ensure the incorporation of the necessary *growth potential*.

2.3 SPACE STATION 2010: AUTOMATION THAT COULD BE

As a first approximation, let us assume that, by the year 2010, the amount of onboard computing capacity will be so large as to put no limit, *per se*, on the number and complexity of computational functions performed onboard the Space Station and companion systems.

Similarly, *as a first approximation*, let us assume that, by 2010, robots will be capable of near-human performance. Moreover, they will be available in various forms, outfitted with a variety of manipulators and end effectors. Some will be capable of crawling, stepping along structures, or propelling themselves through space.

The 2010 Space Station should contain a computer system capable of maintaining the Station, even to the extent of dealing with many kinds of emergency repairs. In the following sections, we discuss various stages or levels of such abilities.

2.3.1 Station Simulation: The Decision Making Process

An important onboard facility would be a computer simulation capable, at any time, of modeling the entire Space Station and its environment in great detail, looking ahead of real-time under current or hypothetical conditions.

The initial building block for this capability is an onboard library of schematics and computer aided design (CAD) representations of every part, tool, and machine aboard the station. This library would be updated constantly. It might be stored on optical disk. It would keep track of the age, wear, expected lifetime, and current status of every part. Doing an annual inventory might be as simple as using a light pen to brush hundreds of exposed bar codes. In the short term, this library/inventory/simulator would allow the crew to know the status and availability of all parts.

Later, CAD images of parts might be used on a small scale to produce replacements on-site, helping to make the Station less dependent on Earth supply. Updated designs might be sent to the Station as *data*, rather than as physical parts. This capability, of course, assumes the enforcement of standard CAD protocols for Space Station contractors to allow representation of all components in the same database. The physical configuration of the Station should anticipate addition of fabrication or computer aided manufacturing (CAM) capability.

The next, more sophisticated step would be to use the library as the basis for developing the complete *Station simulator*. This would have access to a physical database containing information about nearly every plate, beam, fastener, wire, article of clothing, etc., their conditions, locations and velocities, temperatures, currents, and so forth. Sensor devices would monitor key conditions continuously. For others, the values would be estimated by simulations and common-sense reasoning.

Finally, the Station simulator should be able to predict what will happen if, say, a certain beam or tether is removed. The results should go beyond the assumption of a single future scenario. Instead, a semi-intelligent program must explore the extremes of plausible scenarios so that the simulator can quickly find worst cases. To do this requires problem-solving programs with a high level of understanding; they might have to reason backwards, for example, by first envisioning an undesirable configuration and searching to find a sequence of events that could produce it. Once such a sequence is discovered, perturbations can be explored to discover the boundaries for such conditions and determine if a warning should be issued.

By the year 2000, we may have powerful mechanical simulation computers. These would be microchips capable of modeling the mechanical activities of, say, 1000 or more rigid objects in real time, each with its own coordinates, momenta and other physical properties. Some thermal and electrical features may be included as well. Combinations of such computers would make a powerful onboard tool. The simulator will also need other powerful computers to deal with the dynamics of inertial systems.

Human operators should be able to invoke the Station simulator at any time. Also, several versions should be running continuously in the background, seeking to anticipate problems. Whenever a potential malfunction is uncovered, a CAD-type problem-solving system will propose rearrangement of equipment or repairs. In many cases, these will be within the abilities of available robotic-control programs and the simulator may ask permission to make the repair using mobile robots. In some cases, no human supervision will be needed, provided that the robotic manipulations are feasible and verified. Otherwise, the system can arrange for the availability of materials, schedule the removal of other activities from the scene, and mediate the repairs as dictated by local astronauts or distant controllers. This can be done either by remote control or by supervisory control of assembly robots.

2.3.2 The Robot Team

To carry out its many jobs, the overall computer system will use a vast complement of automated mechanical equipment. Robots of many kinds will be perhaps the most sophisticated devices. One can imagine a robot pool with perhaps a few dozen members of varied sizes. Some will stay mostly in specific local areas, doing routine tasks, e.g., maintenance. Others may operate from a "garage," responding to a dispatcher's call, and taking with them the set of end-effector hands, tools, and parts needed for a particular job.

Robots in 2010, some human-like in appearance, and others structured, very differently, will be capable of human-like dexterity and grace. They will be able to move their tool-arms quickly, smoothly, and precisely, performing the required tasks deftly and unerringly.

Such speed and precision will emerge from major fundamental advances in three prime areas of robot technology: intelligent task management, sensing and vision, and manipulator control. In particular, it will happen when we have solved the problem of controlling flexible manipulators using end-point feedback. The result will be a robot that can see what it is doing, as a human does, and will no longer need to be stiff (and massive) to be precise. This payoff is especially great in the weightless and variable force environments of space. Even though the robot's vision processing may fall far short of a human's, special markings and beacons throughout the Space Station work areas will make human-like precision possible. Section 2.5 and Chapter 3 discuss many of these issues.

At the onset of the program, of course, humans will control robots almost joint-by-joint as they do now. But this will soon give way to end-point-command steering when we have mastered the stability and control problems. Gradually, it will be possible to give commands at higher and higher task levels, releasing humans to devote full attention to strategic roles that only they can play.

Later members of the versatile 2010 robot team will be competent aides to humans, carrying out work assignments with only high-level crew supervision. Robots will perform many routine payload deployment, inspection, maintenance, and even repair tasks. Humans will communicate with them through efficient, user-friendly, interface equipment (sometimes at a high level, sometimes in more detail).

2.3.3 Data Management

The Station's data management system must be redundant, resilient, and flexible. The ideal model is a two-tiered system, with a *core network* and a parallel *operational network*. Both networks are multi-node, distributed systems, reconfigurable in software and fault-tolerant. Both use fiber-optic bus technology.

The *core network* handles basic station survival and housekeeping functions, e.g., emergency and minimum power, environmental control and life support systems, attitude and structural control, thermal control, hazard avoidance, proximity navigation support, core communications and telemetry, navigation, and propulsion. The core network is *fail-operational*. Although it is expandable, technological updates are infrequent.

The *operational network* handles user needs, over and above core needs, including scheduling, resource allocation, general communications and telemetry, computational support, experiment monitoring and control, high-precision navigation and pointing, communications with free-flying platforms and teleoperators, and monitoring and control of teleoperator support equipment. The operational network can take over for a failed core network but the chance of this happening will be very low. The operational network often has nodes added and removed as payloads are changed on the station. These reconfigurations are easy, relying on large data busses to plug into, and on standardized organization and communications protocols.

The operational network may make requests of the core network, e.g., for suppression of environmental control functions during experiments, but the core network may refuse the requests. The operational network is *fail-safe* (at least).

2.3.4 System Monitoring

There will be distributed sensors of many types, including pattern-recognition video, with the monitored data evaluated by expert systems that interact conversationally with the crew. The data from the distributed sensors are evaluated by rule-based inference systems which look for anomalous data or unusual trends.

System status and anomalous situations will be reported to the crew through a conversational natural language interface, i.e., voice communication and graphic displays.

The expert system includes an "explainer" that elucidates the computer decisions for the human crew member, including detailed explanations of failure diagnoses. The person can ask for more details or for reevaluations with hypothetical data or rule modifications.

The expert system also has learning ability, in that it can convert the data and decisions provided by people into new data and inference rules for its relational database. The updated rules are integrated into its inference structure, and internal checking routines are applied to verify the continued integrity of its inference logic.

2.3.5 Communications

Later ground communications will use second-generation Tracking and Data Relay Satellites with easy, simultaneous accessibility by a wide array of Earth-based users. High bandwidth laser communications will include many channels (both directions) with voice channels and video links easily available between station and ground. A variety of communications connections also are available for nearby operations and links to free-flying platforms. If there are remote tethered facilities, data flow may be by cable or optical fibers of substantial length.

Infrared sender/receiver headsets will allow any crew member to communicate with any other member, or by voice with distributed computer systems, from nearly any location. Simple spoken routing commands will allow individuals to select any combination of conversants.

2.4 DESIGN TENETS FOR GROWTH IN AUTOMATION

Automation will be a rapidly advancing technology during the lifetime of the Space Station program. It will greatly affect both the ground and the space elements of Space Station operations. Thus a dominating challenge is to design infrastructure that will accommodate this rapid evolution. With such provision, automation will continually improve the Space Station's utility and cost-effectiveness. Machines will do more routine tasks previously performed by humans. Large quantities of information will be available to the crew and support staff. Ongoing developments will make qualitative, not just quantitative, changes in what can be accomplished.

Classical retrofit of the basic station, some years after initial establishment, would in most cases be prohibitively expensive. And yet, a central tenet of Space Station design must be to facilitate the rapid assimilation of new technology, particularly in the fast moving areas of information processing, artificial intelligence, and robotics. This conflict can be resolved by introducing non-traditional design features up front.

A few examples of such design tenets illustrate the underlying philosophy the design should provide

- Standard umbilical utility connections, pervasive both inside and outside the Station, to accommodate the needs of both astronauts and robots. The utilities provided at each point must include access to the Station's computer network, as well as to power, water, oxygen, high pressure gas, thruster propellant, etc.
- Standard attachment fittings at each umbilical location and throughout the Station's interior and exterior to allow automated devices to restrain themselves temporarily.
- Data buses that allow components to be upgraded or replaced as "black boxes" without forcing changes in the overall system as well.
- Bar-code labels for every part of the Space Station, every beam, every fastener and every component, and provide inventory and configuration data for future computer-managed configuration control.
- Highly-visible navigation markings and an upgradable beacon system (both internally for IVA and externally for EVA). These will allow astronauts and automated devices to easily determine their location and orientation and will minimize the cost of automated vision systems. These markings shall be dual human/machine readable, such as standard optical character recognition fonts or normal text plus standard bar codes.

There are many other specific recommendations given elsewhere in this study. But beyond these lists of features, the design process needs an *underlying philosophy*, that is, tenets that cover system specification and can be used to grade contractor performance.

To establish this philosophy firmly from the beginning, *contractor selection and performance criteria must provide for future innovative utilization of automation.*

The definition phase contractors must be directed to apply their efforts to Space Station automation, present (IOC) and future. The quality and quantity of proposed automation should be a major criterion for selecting execution phase contractors. In their proposals, contractors should describe the expected evolution of advanced automation over the life of the program, how they provide for evolution in their design, and how they plan to assimilate automation technology developments from programs such as the DoD strategic computing initiative (DARPA 1983). Contractors should define their underlying philosophies of automation and should indicate how these philosophies will undergo phased implementation over time. The plan should explore synergy, allowing different automated functions to share information.

To meet the requirements for technology transparency, major contractors should design Space Station elements to accommodate operations based on the best technology expected at the time of implementation. Then the contractor should design a cost effective IOC station *specifically intended to be upgraded* in an orderly, time-phased manner to the technological capability-baselined each year. The view of the "year station" will be wrong in detail, of course, but without a growth concept in mind when the IOC system is designed, cost-effective upgrading to new technologies will be impossible.

2.4.1 Utility Support Structure and User-Payload

The Space Station should be divided physically into a utility support structure and replaceable or reconfigurable modules (RRMs). RRMs are the units which contain payloads and accommodate users.

The utility support structure is the Space Station spine the RRMs plug into. This structure will be physically large. It must be constructed or deployed in space. Additions or deletions may be made occasionally to the utility support structure, but it will not be optimized for the interchange of major segments.

The utility support structure will provide only routine functions that are not conveniently supplied by RRMs, and that are not expected to change over time. It will provide power, orbit maintenance, attitude maintenance, heating and cooling, communications with Earth, and intermodule communications. Other services, such as supplying liquid oxygen, may be useful.

The utility support structure will probably not supply a central computational utility for the support of RRMs. The state of the art in computing is too volatile for this to be a reasonable option. However, provision of wide communications channels (e.g., via fiber optics) for data transfer among modules may be a function of the utility support structure.

In contrast, the replaceable or reconfigurable modules must be very adaptive. Replaceable modules will be transportable from Earth to orbit and sometimes from orbit to Earth by the shuttle. A reconfigurable module can be developed in space using payloads specifically carried from Earth, supplemented by creative use of material already on hand, e.g., leftover hardware, external tanks, or experiment modules no longer needed. RRMs may supply their own power communications, etc. and be self-monitoring to avoid interfering with other station operations.

The Space Station will evolve primarily by on-site adaptation, exchange, or addition of RRMs.

2.4.2 Replaceable or Reconfigurable Modules

Reconfigurable modules provide an alternative to the substantial launch expense of sending up entire *replaceable* modules. The argument for this approach follows.

The usual interpretation of *module* is a large, preassembled system--often occupying the entire shuttle cargo bay. It might be a power station, living quarters with life support, or an automated factory. These are *modules* in the sense that they are interchangeable, and independent of each other. Let us call this approach *macro-modularity*.

> *THESIS: Macro-modularity approach does not consider the advantages of space. Macro-modules allow one to "exploit" space in various ways for particular processes. But, generally, they do not exploit space for their own use. They are so bound by previous thinking that, for them, the vacuum, selectable acceleration, and availability of radiation are only nuisances to cope with in expensive and cumbersome ways. Worst of all, they make poor use of orbiting mass, the most expensive resource of all.*

Instead, we should aim toward *micro-modularity*. This is the idea that, whenever possible, large objects and structures should be assembled from smaller ones. These smaller parts should be standardized so that they can be used interchangeably for many purposes, and reused whenever those purposes change.

> *THESIS: The micro-modular approach makes the best use of orbiting mass, over the long run, as we find new applications and projects to do in space. It permits great flexibility in repairing and modifying structures. By reusing materials already in place, it reduces costs and delivery times. It lends itself extraordinarily well to automation, first by remote control and teleoperation, and later by artificial intelligence methods as they evolve--and it can start to be useful without automation. It permits much wider ranges of experiments in the field, possibly eliminating multiyear pauses now forced by macro-modularity.*

The trouble with the old approach is that each system, with its own single-purpose use, involves such a high transportation expense that it must be perfect from the very start. This detracts from many of the goals of a permanent, experimental, scientific Space Station.

If macro-modules must be reconfigured on Earth, transportation cost will be a major consideration. If history is any guide, the following effects will occur:

- Some endeavors will simply be foregone because of lift costs.
- Extra time and funds will be required on Earth to minimize the mass of each experiment. This may also affect the robustness of the equipment.
- Launch costs are also highly length and volume dependent. *Form* and *fit* will tend to dominate the *function* of the experiments in determining costs.
- Scheduling bottlenecks will cause highly inconvenient launch delays.

All of these problems will be reduced considerably if the macro-modules are not perpetually shuttled back and forth between Earth and low-Earth orbit. Instead, reservoirs of mass, volume, volatiles, tools, interchangeable micro-structures, and components should be allowed to gradually accumulate in orbit.

This approach will be particularly useful if the *standards* of micro-modularity are planned from the start, with emphasis on suitability for automation and robotics.

The Micro-modular Standard

All components, wherever possible, should be manufactured in modular form, with conveniently located connection points, and marked for optical and tactile identification with precision fiducial points and identifying bit patterns.

The connection points make it possible to assemble larger units. Advanced fastener technology will be helpful for this, but standard screws and bolts, etc. will do at first. A prototype standard might require regular, unique markers, surrounding threaded *1/4*-20 holes. This is already an international standard for optical equipment.

Fiducial location marks allow important new possibilities. Every part can have a unique identification so that a computer system can keep track of all materials. Universal product (bar) codes already are a proven technology. We do not have to wait for a more advanced computer-vision system to mature.

As we have stated earlier, a computer database could keep track of every part and every connection point. In many cases, locations can be specified to within a micrometer. When a new device is needed, a computer-aided design system could automatically investigate the availability of components and materials. It could even propose to borrow them from other systems, and estimate the cost of the resulting downtime.

2.4.3 General Automation Replaceable Module

Advanced automation (Artificial Intelligence--AI--and robotics) is a multipurpose technology that applies to every operational aspect of the Space Station. There is, therefore, a logical argument for treating AI and robotics as a utility and making them part of the utility support structure. This must be avoided because of the rapid rate of change in this field. Space Station design should instead provide for a general automation replaceable module (hereafter referred to as the module). Every few years a new module will replace the old one.

At some ~~point~~, the module will include a "robot pool" (like a motor pool), facilities for servicing and repairing robots, computers and programs for controlling robots, symbolic computers and AI programs for general use, and perhaps a numerical supercomputer utility.

Objects that are logically a part of the module may, of course, be physically attached elsewhere, but controlled from the module. An example would be a fixed robot manipulator attached to the utility support structure on a location remote from the module or mobile robots that travel about the Space Station.

2.4.4 Stages of Automated Assembly

STAGE 0. *Manual uses.* Assemble parts by hand, if necessary. Furthermore, the astronaut could hold a mobility device designed to locate and grasp anywhere from 1 to 4 connection points (using the computer database to select them, and to supply their approximate locations and load capacities). This would lead to new, fast, reliable construction methods which would otherwise have to wait another generation to work with ordinary, unprepared materials.

STAGE 1. *Teleoperation.* Use a semi-automatic mechanical hand to link the connection points and manipulate structures.

STAGE 2. *Direct Supervision.* Provide automatic assembly and operation methods using direct human supervisory control.

STAGE 3. *Task Supervision.* Perform automatic assembly of more complex structures, with only task-level human supervision.

STAGE 4. *Adaptive Design.* Use CAD and planning programs in space to design new structures from a database. Components can be borrowed from inactive equipment and experiments and restored later.

STAGE 5. *Autonomous Development.* Employ artificial intelligence, as it becomes available and adaptable, in the non-micromodular components of the Space Station. Possibly adapt CAD to actual fabrication of components on site.

2.4.5 Hierarchical System Architecture

There is always a temptation to design and build a system with a central computer(s) that is optimal by fixed criteria. The result is usually a flat, *monolithic system design.* It tends to be hard to understand and hard to maintain or modify. This sort of optimization and minimization is taught in engineering schools, and it is appropriate for mass-produced, expendable products. Because it minimizes the cost of hardware and the high cost of transportation to space, there is a great temptation to use this style of design in space systems. The Space Station, however, is to be a long-term system that can *evolve.* Designers need not be as tyrannized by mass and volume (form and fit) if a piece of hardware is to be launched once, not repeatedly. Short-term inefficiencies (such as extra weight) should be accepted to achieve long-term flexibility.

The *hierarchical system* is well suited to managing large, complex domains. Any level of the hierarchy should be capable of performing its function without the intervention of any higher level. However, any level should also be capable of being partially, or almost completely, controlled by the next higher level. Biological organisms use this kind of hierarchical organization. For example, breathing is autonomically controlled by the brainstem, but it can be overridden (within limits) by emotion (a mid-layer phenomenon), or even controlled consciously by the cortex (the top layer). In the event of unconsciousness, lower level functions remain reliable. With the Space Station, the aim is to produce a system that is understandable, maintainable, reliable, and modifiable.

2.4.6 The IOC Space Station Design

The IOC Space Station design should make things easy for robots, rather than relying on the development of arbitrarily skillful robots. *Robot mobility must be a central design consideration* in both the utility support structure and in all replaceable modules. The following are some examples:

1. Think through assemblies, disassemblies, and repairs that might be done in space and have someone try to design a robot to do each of them. The exercises alone will bring out design aspects that might otherwise have been ignored. It will also make convenience for robots a criterion for good design.

2. Design the main structure so that simple robots can move about on it and gain access to every outside part. Perhaps with clever design, the frame itself can be the scaffold. Wheels, invented to carry gravity-imposed loads, may in low or zero-gravity be inferior to a legged system that moves from one standardized grasp point

to the next. If the structure has the proper geometry, the legs could be very simple. Better to design the structure and the mobility system together than trying to design complicated, heavy, crawling robots versatile enough to move over an arbitrary structure.

3. Minimize distribution networks, i.e., pipes and wires, to simplify construction, repair, and modification. Where there is a choice between a central plant with a distribution network and distributed small plants, prefer the latter. Examples include power, cooling, fuel, and communications. Note that solar power and access to black sky for heat dissipation are already distributed by their very nature. Communications by lightbeam eliminates some of the need for a wire network. Usually the only reason for a distribution network is economy of scale at the central plant. In space this is often outweighed by the complexity, conduit weight, loss of redundancy, and unreliability of joints, entailed by a network.

2.4.7 Competition

This report explores and emphasizes the application of automation and robotics to many aspects of Space Station design, operation, and growth. The recent and continuing explosive growth of capabilities in microelectronics encourages us strongly. However, we should remember that applying an expert system or a robot to a given task or function may not necessarily be the best solution. In many cases, good mechanical design or simple hardwired circuits will meet a wide range of needs. A healthy competition must be maintained between A&R proponents and more classical designers. Of course, access by both groups (often of overlapping membership) to advanced CAD systems both speeds and sharpens the competition.

The Panel wants to emphasize that optimizing the Station design should not preclude evolution and growth.

2.5 REQUIRED TECHNOLOGY ADVANCEMENTS

Reaching the cost-saving levels of total automation described above will take time. For implementation in the Space Station by, say, 2010, NASA must invest special congressional funds *now* in several key areas of *fundamental technology*--in computer automation, expert systems, robots, and man-machine interfaces--that will produce the specific crucial leverage needed. NASA must develop better ways to quickly space-qualify off-the-shelf industrial technologies. Even broader opportunities will be afforded by designing the Station to accommodate terrestrial technologies.

The reader can recognize these key technology advances by comparing today's systems of computer automation and robots with the corresponding future capabilities predicted in section 2.3. Special aspects of the Space Station project indicate where NASA's base-technology investment should focus to achieve the most effective leverage on the broader national automation effort.

2.5.1 Robotics

Chapter 3 covers robotics in detail. Here we will cover only some of the most important general points.

Clearly, robots could undergo truly revolutionary changes. In 1992, they will still be crude, clumsy, unthinking machines, little better than today's robots, and they will see limited use. By 2010, they *could* have developed into automatons that perform at near-human levels in a broad range of areas.

Generally, today's "robots" are just single arms with a simple, pliers-like gripper or some other elementary tool. Only a limited repertoire of sensors are available. Visual systems (standard video cameras or range-finding systems) exist, but only a tiny portion of the information in the images can actually be understood and used. Today's robots only perceive the world as a source of events, and cannot understand their interrelationships. Robots *do not maintain internal models of their environment.* The programming languages used to control today's robots are not sophisticated enough for a truly flexible response to external situations that change or are not anticipated, since they incorporate only a few primitive motion control commands. Sophisticated tools for analyzing sensory input are generally unavailable.

By 2010, in contrast, robots ought to be near-human in their manipulative, task-management, and sensory capabilities. Indeed, in several ways, robots can be significantly better than humans at a wide range of tasks.

This will not happen by itself. *Fundamental advances are needed* to move from the crude state of robot technology that will be available in 1992 to the level that *could be available. These advances would make the 2010 Space Station much more effective and much less costly to operate.*

Manipulation: Today's robots are crude and uncoordinated. They must use manipulators that are massive and, hence, move ponderously. Momentum and inertia are severe problems. By contrast, a person's arms and fingers are light and *limber*. This is an enormous advantage, especially in the zero-gravity space environment. Movements can be much quicker, more deft, and more precise. Humans control their arm and finger movements by using feedback gracefully from many sensors, at their end effectors and distributed throughout their structure. Only recently in the laboratory have we begun to learn how to achieve fast, stable control with distributed systems of sensors. Technology advances in manipulators are *crucial*.

Sensing: Humans possess kinesthetic sensors that indicate the configuration of the arms, fingers, etc.; sensors of forces and touch and fine texture, stereo sound, and temperature; and a prodigious vision capability. To give all these (and several more) to tomorrow's space robots, technology advancement is needed in

- Sensors of *manipulator configuration* that go far beyond today's rigid joint angle encoders.
- Sensors of the *distribution* of forces and torques.
- *Finger-tip sensors* that can recognize the texture of a surface.
- Discriminant systems to *sense radiant energy* of many wave lengths, from radar to light.
- Systems of visual *perception* and real-time visual image *recognition*.

An important part of any A&R technology advancement program will be efforts to improve both sensors and their modeling power. Manipulators for space applications are another key area.

2.5.2 Information Management

Chapter 4 emphasizes the importance of well-targeted technological advances in information management. In particular, it singles out the development of expert systems as the key to an efficient, expandable, increasingly intelligent information management system for the evolving Space Station. This recommendation is made in spite of the fact that current expert systems generally require several years to develop, debug, and optimize, yet still run slowly and require extensive human interaction.

Nevertheless, expert systems are workable artificial intelligence techniques that offer significant economies in their present form. The hardware and software advances that could move them nearer to providing real-time results, self-questioning and answering capabilities, and common-sense (as well as logical) decision making are visible on the technological horizon. Since both industry and academia are becoming increasingly involved in the development of such systems, NASA's A&R program could provide a significant focal point. This would both assure success for the IOC information system and lay a solid foundation for the autonomous system of the 2010 Space Station.

Establishment of a NASA knowledge engineering laboratory is recommended to define the systems, collect and codify knowledge, develop automated methods, and accelerate the intensive development of the hardware and algorithmic and knowledge representation software. Not only should this facility provide the latest and best equipment and libraries for symbolic computation, it should also serve the needs of special teams formed from NASA personnel familiar with mission operations, and from experienced astronauts, and knowledge engineers charged with developing systems. It should be part of a high data-rate network of industries, universities, and other NASA centers to help focus the overall program.

Modularity and standardization are the essential ingredients for an information management system that can grow with the Space Station. Insofar as possible, principal software and hardware subsystems should be designed for self-contained operation. They should also allow control by higher levels, and present standard interfaces to other systems. A structure of this type will both facilitate add-ons and make upgrading of computing hardware and software possible, while the system continues to operate in a restricted mode above core level. In addition to standardized interfaces, excess capacity is needed, especially in the initial network configuration, and all units should be designed to accommodate increasing parallelism of function. Without these features, it is unlikely that the desired degree of autonomy can be achieved by 2010.

It is also important to space-qualify commercially available computing and peripheral equipment through early demonstration projects, and to delay final IOC selections as long as possible. The technology is advancing at such a rate that a few years of additional development could make a major difference in the size, power requirements, and operational capabilities of the units selected. An open-ended, modularized system with hierarchical control should make this possible.

As to language standardization, performance tests should be carried out as soon as possible to choose a single language for general operations (perhaps Ada or C), and a single language for artificial intelligence applications (possibly LISP or PROLOG). Special dialects for robot control, human interfaces, and other special purposes could then be translated into one of these, automatically, for execution. Adoption by NASA of one language in each category, and the establishment of criteria for their use, will do much to promote further standardization and development.

Finally, a permanent testbed and development facility for the Space Station information management system should be established at a NASA center in the near future. All subsystems of the Station should be tested in this facility before installation, and should be duplicated in it to build up a redundant Earth backup system linked to the Station through broadband microwave channels. Workstations with advanced simulation functions should be provided, and arrangements should be made at the outset to store the data accumulated during the design and operational phases. Portions of this permanent and comprehensive database can then be duplicated onboard the Station.

2.5.3 Earth-Based Design and Production

Chapters 5 and 6 deal with the ways in which automated techniques will help leverage the design and manufacturing of space facilities, especially the Space Station. Ways must be found to make the production of space hardware quicker and less expensive. Automation in the design center and on the shop floor will entail several new technologies. Here we cover only the most critical of these.

Standardized CAD/CAM: Many companies are vitally interested in establishing standard methods of representing data in CAD and CAM systems. However, most companies are too small to effect standards alone. NASA has the economic power in the Space Station program to establish and enforce standards if they are developed in concert with industry. This could have a major influence on the rate of CAD/CAM development and also on the ability of contractors to deliver new parts rapidly and at low cost.

Mass and volume: Previous restrictions on lift capability have forced NASA into extensive design programs to severely restrict weights and sizes of components. Thus nearly every item was "special" and correspondingly expensive. The higher lift capacity of the STS will allow NASA to use more standard industrial components. In the case of *lift once* systems, such as the Space Station, mass and volume design constraints need not be as restrictive as with sortie vehicles, such as the orbiter.

Space-qualifications: As discussed elsewhere, use of standard industrial parts can also result in a much more rapid development cycle in Space Station equipment and modules, provided *space qualification* can be speeded up.

2.5.4 Reliability and Interchangeability

Robots and computers must be made increasingly rugged and reliable. Any major piece of equipment that must be "swapped out" (replaced by a new part sent from Earth) will compete with other items in the inevitable launch bottleneck. Subcontractors charged with building station parts should be encouraged, wherever possible, to include interchangeability as a design criteria.

2.5.5 Simulation

Continued progress must be made toward the advanced simulation technology described earlier in this chapter. Space Station crew members should be able to model the effects of current trends or proposed changes in station parameters. Processors should be dedicated to a perpetual search for failure mode scenarios and ways to prevent them.

2.6 PRE-IOC TECHNOLOGY DEMONSTRATION PROJECTS

Advancement of automation and robotics throughout the Space Station requires early demonstrations of semi-autonomous robots, and expert systems in the pre-IOC time frame. This section presents several such demonstrations (summarized in Exhibit C in the Executive Summary). Many of the terms are defined in the Glossary.

2.6.1 Pre-IOC Robotic Demonstrations

A number of demonstrations could be conducted on Earth in the near term, and some later transferred to space. Candidates for such demonstrations include the following:

Near Term (Present to 1988)

Earth-based demonstrations:

1. Automated assembly of Space Station-like parts under human supervision.
2. Automated inspection of space structures.
3. A robot helper to assist astronauts with routine maintenance tasks.
4. Means to identify critical human factors of man/machine interfaces for the Space Station.

Mid Term (1988-1992)

1. Specific advances in teleoperation of robots demonstrated in space, working perhaps from the Oak Ridge Advanced Teleoperator System or other new-generation teleoperators. Such demonstrations on real cargoes would increase confidence in IOC systems.
2. Semi-Autonomous Robots: A small computer-controlled, sensor-equipped robot to carry out onboard demonstrations in the shuttle bay under astronaut or other high-level supervision. (Boxing the experiment in a container could minimize space qualification effort.) This could demonstrate important new capabilities, such as fast, precise end-point control of lightweight flexible manipulators and mobile-robot control in micro-gravity.
3. Introduction of limited voice control to assist human operators.
4. Testing of a milli-gravity manipulation device.
5. Real-time simulation of shuttle or Station systems.
6. Early demonstration of techniques for in-space parts adaptation and fabrication.

Far Term (1992-2000+)

Post-IOC deployment demonstrations:

1. Multiple cooperative robot systems in the space environment.
2. Advanced sensor fusion for perception.
3. Integration with expert systems for self repair and self diagnosis.
4. Autonomous robots (starting at IOC).

Chapter 3 discusses some of these demonstration projects further.

2.6.2 Pre-IOC Demonstrations of Expert Systems

It is important that both the IOC and its successors take advantage of automated systems that "learn." Self-programming software and databases offer ways to improve and update automated systems smoothly to meet new demands, while requiring less human intervention.

Expert systems are a key element in this area. Chapter 4 discusses them in some detail. Here we will list only a few *possible demonstration projects* that might be performed, pre-IOC, to maximize confidence in, and use of, these promising technologies.

Some of the suggested demonstrations, listed in Exhibit C of the Executive Summary, are discussed below:

Pre 1989 demonstrations:

In spite of the short time scale, some versions of space relevant expert systems may be demonstrated before 1989. For instance, simple expert systems might help in crew activity planning or in health status monitoring.

Ground-based test beds for station power, life support, and thermal control should, from the start, include expert systems for utilities monitoring. This will ensure a smart management capability when the IOC system is installed.

New fault isolation techniques should be tested, possibly in space hardware.

Post 1989 demonstrations:

As IOC approaches, it should be possible to test and verify more advanced expert services. Examples might include voice control systems, onboard inventory control and station simulation, a flexible experiment manager, and internal and external communications monitoring.

2.7 CONCLUSION

Subsequent chapters will explore many of these ideas further. The important issue is that the Space Station is a means, not an end in itself, and it must not be frozen into an optimized design based on early 1980s technology.

If we are to achieve advances possible by the year 2010, we must begin a program now of fundamental technology advancement. This program should be sheltered from the day-to-day demands of Space Station implementation and operations, but still interact vigorously and creatively with those responsible for the basic IOC Space Station.

Especially, we must be sure that the *circa* 1992 Space Station is capable of readily accepting higher levels of automation that emerge from the technology advancement program.

2.8 REFERENCES

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Chapter 3

ROBOTICS

3.0 SUMMARY

Robots can increase the Space Station's capabilities and cost-effectiveness by

- Handling routine tasks and minimizing the use of crew time.
- Performing dangerous work that involves hazardous materials or extravehicular activity.
- Carrying out servicing activities such as resupply and maintenance.
- Allowing for the development of space-based repair and manufacturing facilities.
- Performing housekeeping functions such as inspection of the spacecraft itself.
- Handling materials and performing other functions that are difficult for humans in the micro-gravity environment.

Current robots have limited ability and intelligence. They can perform only simple, predefined tasks by themselves. The Space Station will need more capable systems that can operate more independently. It will also require simpler, more natural human interfaces than are now available. The robots must be able to use computer aided design/computer aided manufacturing (CAD/CAM) databases, respond to generalized commands, and perform self-calibration, self-diagnosis, and self-repair.

The areas in which NASA should concentrate its technology advancement efforts, in order to achieve these capabilities, are

- Producing space-worthy robots with autonomous capabilities.
- Combining the function of autonomous robots with remotely controlled manipulators (*teleoperators*) to create hybrid systems.
- Improving user interfaces to include color and stereo displays, force feedback, and voice activation to make the remote operator feel almost present in the workplace (*telepresence*), and to allow easy human control at the highest possible task level.
- Manipulating objects in micro-gravity.
- Developing systems for making manipulators work together.
- Improving robots' abilities to sense and control their environments, through better sensors, perception, actuators, manipulators, and end effectors or "hands."
- Developing self-contained, self-powered mobile systems that maintain information on their current status.
- Creating systems that have sufficient dexterity and understanding to assemble extended parts.

Achieving these advances will require vigorous and continuing technological effort. In some fields NASA must create excellence that *leads* the world. In others it may acquire needed technologies by *leveraging* or *exploiting* outside developments with internal expertise. Exhibit G contains specific categories divided in this way, along with recommended baseline and minimal funding levels. The Delta column is the difference between the two effort levels, and the Fallback Order is the order in which categories should be reduced or dropped (lowest numbers first) in case of funding disruptions. Within divisions, categories are listed in order of importance. Each category appears only in the highest applicable division. We assume that NASA should also leverage or exploit developments in areas in which it must lead.

Exhibit G

A&R Technology Program: Man/Machine-Robotics

	Category	Baseline Program ($M/year)		Minimal Program ($M/year)		Delta $M/year	Fallback Order
		Research	Demos	Research	Demos		
NASA must *lead*	Space Manipulators	10	2	6	2	4	5
	Materials Handling Technologies	8	2	4	2	4	5
	Robot Mobility in Space	8	2	4	-	6	5
	Man/Machine Interfaces	25	4	11	2	16	4
NASA applies *leverage*	Robot Sensors/Integration	16	4	10	2	8	3
	Reconfig./Repair Robots	3	-	-	-	3	2
	Hi-Level Robot Progrm. Lang.	6	-	-	-	6	1
NASA can *exploit**	Factory Robots	< 1	< 1	-	-	-	-
	Lightweight Motors	< 1	< 1	-	-	-	-

* Examples of potential off-the-shelf purchases.

3.1 INTRODUCTION

This chapter concentrates on technology advancements in robotics that are necessary for the Space Station to achieve its optimal level of automation. NASA can build on the large amount of work done in robotics in recent years. Still, this is an immature field requiring extensive further development. NASA must play a key role in seeing that both general and space-specific capabilities are available to fit its needs.

Generally, today's robot is just a single arm. End effectors, e.g., elementary tools such as a simple pliers-like gripper attach to the end of the arm. The robot can be made mobile by placing it on a simple, wheeled vehicle programmed to run along a set path. Available sensors include ultrasonic proximity sensors like those used commercially to open doors, touch-pads that can form a crude tactile image of an object in contact, and instrumented wrists that perceive the forces applied to the robot's hand. The robot can obtain visual information from either a standard video camera or a range finding system. However, its ability to process this information is usually quite limited because of restricted image processing capabilities.

The programming languages used to control today's robots are not advanced enough to allow flexible responses to changing or unanticipated conditions. Normally, these languages have only a few simple motion control commands, such as "move from point A to point B along a straight line." Although actions may depend on information received from sensors, e.g., "halt as soon as an object is touched," they seldom provide sophisticated tools for analyzing sensory input. For example, making a robot grasp a door handle and open a door, to say nothing of coordinating two hands to remove the plastic wrapping from a box of film, is still a challenge for the laboratory.

Today's robots do not have an internal picture of the world around them. All they do is respond in an isolated manner to individual events as they occur. Robots do not yet have any sense of context, continuity, or history. In other words, they do not see themselves as part of an overall environment.

In a possible scenario for 2010, by contrast, robots are near-human in their manipulative, task management, and sensory capabilities. The primary exception is visual information processing, where human abilities are likely to be out of reach for a much longer time. Indeed, in some ways, robots are already far more adept than people. They can use finely-structured range-to-object information, and they can swap special-purpose end effectors of different sizes and configurations. These and other advantages may increase greatly.

Advancement is necessary to move from the crude state of robot technology that will be available in 1992 to the level that would make the 2010 Space Station much more effective and much less costly to operate.

Let us begin examining the needed development by first considering manipulation. Manipulators used in today's robots are typically massive (in order to be stiff) and hence ponderous in their movements. Research should be directed toward light and limber manipulator systems with high strength-to-mass ratios that can use feedback from many sensors. Fast, stable control with non-colocated systems of sensors will be necessary.

Humans have a marvelous array of sensors: kinesthetic ones that indicate the position of the arms, fingers, etc.; separate sensors of force, touch, and texture; stereo sound; smell; temperature; and of course, above all, vision. To give all these (and several more) to tomorrow's space robots, research is needed in the following areas:

- Sensors of manipulator configuration that go far beyond today's rigid joint angle encoders. These should be able to indicate in detail the bending and torsional configuration of highly flexible manipulators, like the reader's own joints, and the configuration of the "tendons" controlling them.
- Sensors of the distribution of forces and torques throughout a machine's arms and fingers, with local computing to interpret the combined data.
- Fingertip sensors that can detect and reconstruct in three-dimensional detail the texture of a surface with which they come in contact, just as human fingers can.
- Discriminant systems to sense radiant energy at many wavelengths, from heat to light. These would allow not only proximity-ranging to nearby objects, but also a determination of their shapes.
- Visual recognition of objects, which is relatively easy now, and real-time visual perception, which has many generations to go and warrants major effort.

We can expect to have available, in the next two decades, highly-developed factory robots that can perform repetitive manipulative tasks with speed, accuracy, and reliability in *structured* environments. They will have high quality visual, acoustic, tactile, force, torque, and other sensors. These machines will be programmable in two modes: (1) by a person leading them through the desired sequence of motions either directly or through an exact model, and (2) off-line, by using a CAD/CAM database containing models of the robots, workpieces, and parts of the environment. Multiple processors will control dynamic behavior of joints, and later the end effectors, to orchestrate and coordinate motions, and to communicate with other computers and devices.

In later decades, with development of more nearly autonomous robots with greater capabilities, the role of astronauts will change. They will operate at increasingly higher levels of control. This gives extreme importance to the development of improved man/machine interfaces, a topic to be discussed in detail later.

The following sections examine technology areas in robotics critical to the advancement of automation on the Space Station. We start with a discussion of terminology, concise descriptions of the current state, and projections of emerging technologies.

3.1.1 Teleoperator Systems

The term *teleoperator* commonly refers to a multi-jointed manipulator system, whose actions can be controlled continuously and in detail by a human operator, either remotely or close by. The first such machines were used for handling nuclear materials. Now, astronauts use the remote manipulator system (RMS) of the space shuttle to help launch and recover satellites. Other current applications include remotely-controlled submersibles, aircraft drones, and materials-handling systems for remote or hazardous environments.

As previously discussed, robots currently have limited capabilities in unstructured environments. Under such conditions, teleoperation, i.e., *continuous human supervision at some level*, is necessary. This is seldom worthwhile in Earth-based activities unless the task is too dangerous or impossible to do except by remote control, or where manpower is severely limited. All of these conditions, however, apply in space.

Early space systems might combine technology from factory robots with advanced teleoperators for use in less structured environments. The astronaut could guide the resulting hybrid machine to the vicinity of a task, and then invoke standard programs. These will allow the machine to work semi-autonomously using its own adaptive sensors to solve minor problems such as misalignments. Position and angle references can be updated by scanning easily interpreted markings distributed all over the Space Station.

Embedded computers smooth the motions of modern teleoperators in response to human control. Electronic sensors help the remote operator guide the devices and sense the forces exerted on workpieces or other objects. Still, state-of-the-art teleoperators require total, detailed human supervision; being excruciatingly slow and ponderous, they often produce deep operator fatigue after just a short period.

The principal long-term goal in teleoperation is to make human operators feel as if they are actually present at the workplace. We call this *telepresence*; Section 3.3.3 discusses it in detail. Improvement and integration of multiple sensors, interfaces, and manipulative controls may eventually make operators almost as productive through remote control as on the scene.

3.1.2 Hybrid Teleoperated Robots

A promising approach for space, particularly while robots are still primitive, is to use a *hybrid system* that combines teleoperation with some autonomy. Such a system is sometimes called a *telerobot*.

Advanced visual telepresence could allow investigators on Earth to conduct experiments as if they were actually onboard the Space Station. *In this situation*, robots will perform repetitive experimental tasks automatically, while researchers concentrate on more important issues. The hybrid approach will allow the investigator to get a feel for conducting an experiment in the space environment. Gradually, with the inclusion of more intelligence, robots can begin to perform such tasks as inspection, repair, maintenance, and construction. This, of course, will depend on advances in several key technology areas that will be discussed later.

The Space Station will have associated facilities (co-orbiting, remotely tethered research observatories, etc.) requiring periodic repair, cleaning, and maintenance. Given the life-support and safety problems of human EVA and the hazards of handling materials such as cryogens, the servicing of these systems (and of satellites) will be a prime candidate for early automation. Telerobots are well suited to tasks such as cleaning lens elements and replacing hazardous consumable materials. They can also service transport vehicles and refurbish and repair satellites. Another potential application of automation is the establishment of manufacturing facilities in space for crystal growth, integrated circuit chip fabrication, and pharmaceutical production.

A facility for assembling large structures is another area where telerobots can enhance human productivity and safety. Section 3.2.1 addresses the development of such a facility.

Three classes of telerobots can be considered for near-term applications. First, limited capacity, transportable hybrids for use within the Space Station could perform materials-handling and monitoring tasks, such as loading and unloading test samples in biological and pharmaceutical experiments. They could also move materials and products in experimental manufacturing systems, and help with cleaning, waste handling, and process monitoring. Repair operations such as removal of panels and replacement of modules are other possible applications.

Larger, externally attached telerobots, such as the Space Transportation System's advanced RMS equipped with force and optical end feedback, could load and unload shuttle payloads, perform automatic refueling, do external repairs, and help assemble structures. The robots should be movable to attachment points distributed around the Station.

Finally, teleoperators incorporated in free flyers could perform simple satellite servicing operations. They could also help in monitoring and inspection by bringing special sensors into position at astronaut command.

In conclusion, hybrid systems afford a natural transition from total operator control to autonomous operation. They can benefit Space Station operation by freeing crew members from effort-consuming, repetitive, or hazardous tasks. With telerobots, staff members can accustom themselves to working in the space environment and thus gain the experience required to tailor future experiments and tasks more efficiently. Finally, the dual nature of telerobots offers additional safety. In the event of mechanical, electrical, communications or software malfunction, autonomous actions by the robot or human telepresence can offer multiple ways to control telerobot.

3.1.3 Autonomous Robots

Finally, in the long term, the evolving network of space facilities will feature more and more systems that do not require supervision. Initial automated systems will be stationary units, such as for utilities and life support. Advances in robotics and information management will lead to extremely versatile autonomous machines that move about, perform experiments, or reconfigure, repair, or assemble the Station itself. Planning for them must start now. For that reason, we recommend that an autonomous mobile robot be present on the IOC station. The initial autonomous robot will be limited in capabilities, but can be useful (see Appendix 2-A).

The following sect[illegible] will describe these ideas in more detail, first in illustrative scenarios and then in a [illegible]ssion of needed research and development.

3.2 SCENARIOS

This section presents four scenarios (assembly, inspection, satellite servicing, and manufacturing) illustrating potential uses of automation and robotics on the Space Station. Each considers different stages of Space Station evolution to demonstrate how technological advances will affect and benefit our ability to do things in space. The scenarios deal with different functions and physical locations, i.e., within the Space Station, external to, but attached to the Space Station, and incorporated in a free flyer. The reader should also refer to the reports by design and technology contractors of the Automation Study for similar projections.

3.2.1 Assembly Scenarios

Construction of large structures requires the assembly of many modular elements arrayed upon trusses. Trusses can be assembled at the Space Station or obtained from the shuttle in deployable form. As one possible approach, two telerobotic arms, working together, combined with an assembly pallet or holding fixture, will allow rapid construction and minimize labor requirements. Assembly telerobots can initially be part of the construction base. Later, they can be part of an OMV (orbital maneuvering vehicle) for transport to and from remote work sites. As they evolve, telerobots will do increasingly diverse tasks.

Assembly of the Space Station is the first major construction task. Then, at IOC, platform construction and enhancements begin. Assembly of space structures for advanced missions such as exploration, observation, processing, and experimentation will be done during the ensuing years. The general goal of automated assembly and construction is to increase the effectiveness of astronaut labor, reduce EVA time, and provide more flexibility to handle the unforeseen problems typical of large, complex construction projects.

IOC Assembly Scenario

Astronauts will assemble the Space Station in EVA with the assistance of large, coordinated teleoperators similar to the current RMS but equipped with new, "smarter" end-effectors. Astronauts will generally control the teleoperators completely. They will have only limited learning capacity for unattended performance.

Astronauts will have primitive voice control over the teleoperators and the OMV that ferries subassemblies into position. A CAD/CAM terminal at the worksite will provide detailed assembly instructions. Parts will be labeled to aid in identification. Telepresence capabilities embedded in the smart end effectors will allow testing of the integrity of joined pieces during construction, and will aid in recognizing assembly interferences and other anomalies.

New technologies needed to perform assembly and construction in this highly structured environment include

- Development of telerobot learning techniques.
- Advanced end effectors incorporating telepresence.
- Primitive voice control of teleoperators and OMV.
- CAD/CAM database for assembly.
- Accurate, reliable manipulation of objects in micro-gravity.

Year 2000 Assembly Scenario

Construction of enhancements, modifications, and special mission hardware will require the ability to work with less structured designs and diverse assembly concepts. Less EVA will be required since both large and small telerobots can be directed from inside the Station. An OMV-like vehicle, the construction and assembly maneuvering unit, will have a limited life support system, twin teleoperator arms, a CAD/CAM/CAE (computer aided design, manufacturing, and engineering) terminal, and spare parts and tools storage. This OMV will ferry remotely controllable tools and parts from subassembly sites to assembly points. Onboard tools will check dimensions and alignments of structures during construction.

End effectors will have micro-motion and micro-manipulation capabilities along with tooling modules. These will provide a limited on-site machining and forming capability. All teleoperators will be able to work with smart tooling and clamping pallets both in subassembly operations and during on-site construction. Astronauts will spend most of their time at a computer workstation using the extensive database, expert systems, and automated planning and simulation tools.

New technologies needed for achievement of this scenario are

- Expert systems embedded in CAD/CAM/CAE databases.
- Improved robot perception and control.
- A new maneuvering vehicle with considerable utility.
- A localized capability to measure precision distances.
- Advanced machine vision and optical image processing.
- Tools for small scale machining and forming.

Year 2010 Assembly Scenario

Building large, complex structures for mission use will require adaptive assembly, working with many designs, and dealing more autonomously with unstructured construction plans. To prevent bottlenecks and lift surcharges, necessary small parts must be altered or fabricated on-site, using a CAM-driven machining center. Telerobots will perform joining tasks such as resistance spot welding, electron-beam welding, and continuous joint and seal forming. They will also have advanced end-of-arm systems enabling localized forming and machining, telepresence, and improved perception.

Astronauts will mainly supervise assembly from inside the Station or from the construction and assembly maneuvering unit. Access to advanced CAD/CAM/CAE systems with extended expert systems, dynamic interactive simulation, and automated task planning will minimize EVA time and astronaut labor.

The technologies required to make this scenario feasible include

- Extended expert systems.
- Advanced CAD/CAM/CAE technologies.
- End effector modules to include welding, cutting, machining, and forming.
- Space Station fabrication and machining facility driven by a CAM system.

3.2.2 Space Station Inspection and Repair Scenarios

Inspection of the Space Station's hull and associated structures is critical, and yet thorough flaw inspection is a time-consuming and labor-intensive process. Its automation requires precision manipulation of sensitive and delicate probes and sensors over large surfaces. Many of these must be in contact with or near to the area under scrutiny to allow detection of subsurface flaws. Automated inspection also requires automatic data acquisition and analysis to quickly define flaw presence and severity. Repair after detection will involve a variety of procedures to patch micro-meteorite damage or fatigue cracks and repair other effects of aging, as for example, in composite materials.

IOC Repair Scenario

In the 1992 time frame, the use of telerobots to inspect the hull and structure appears to be feasible. The Space Station computer will periodically direct the astronaut to inspect a particular area following a set schedule. The astronaut will manually position a telerobot similar to the RMS on an exterior surface. The telerobot's end effector will contain interchangeable modules consisting of sensors such as high resolution machine vision or surface contact probes, depending on the type of material being inspected. Automatic inspection, once begun, should no longer require the astronaut's attention. A typical procedure might involve sweeping over an exterior surface (e.g., a solar array or thermal radiator) at low velocity using high-resolution machine vision. The inspection system would use CAD/CAM data for the current hull sector to direct the RMS and avoid obstacles.

A laser beam could sweep the inspection path, highlighting cracks, holes, and surface blemishes. A second camera in the end effector could use high magnification lenses and a laser-specific filter to see flaws in great detail. Upon finding a flaw, the inspection-path routine would halt, and a more detailed subroutine would be activated, perhaps employing eddy-current, electric-current, scanning electron microscope, X-ray, or other inspection techniques.

If a detected flaw exceeds predetermined size limits, the astronaut would be summoned to investigate and make repairs. All flaws, regardless of size, would be characterized, and the resulting data stored in a computer database for ground-based structural engineering groups and for daily review and repair planning by the astronaut team.

In repair mode, the astronaut would reconfigure the RMS end effector by removing inspection modules and replacing them with repair units such as sealant and adhesive dispensers and simple patch applicators. Telepresence features in the end effectors would allow the critical positioning and application of pressure-sensitive patches.

The scenario requires the following technologies well in advance of 1992:

- End effectors allowing rapid module interchange.
- Improvements in high-resolution machine vision and high-speed data processing.
- Development of a knowledge base for hull failure mechanisms and degradation phenomena of key surfaces (e.g., hulls, solar cells, windows, mirrors, thermal radiators).
- Probes for efficient inspection of composite materials.
- CAD/CAM database for hull and structural details.

Year 2000 Repair Scenario

The year 2000 would see telerobots, with more autonomy and with the ability to inspect and repair larger, more complex structural areas. This will be accomplished through the use of well developed CAD/CAM databases and an in-depth knowledge of areas of the Space Station with high incidence of flaws. The robotic inspection system's end effectors would have extensive capability for automatic repair of most surface flaws and some structural flaws through simple patching routines. Complex or large hull repair would require astronauts to use the RMS as a teleoperator. The technology required to achieve this by 2000 includes

- Improved adaptive control for micro-motions within end effectors.
- Development of detailed Space Station CAD/CAM databases.
- Continued improvements in high-speed, high-resolution machine-vision systems.

Year 2010 Repair Scenario

The year 2010 scenario would see the inspection apparatus become an adaptive, autonomous robot able to inspect entire structural and hull features without human attendance and with very little direction. The inspection robot would still be usable as an astronaut-guided teleoperator. In addition, it would have extensive independent repair capabilities ranging from the application of surface patches to the large-scale removal and replacement of panels. The robot's role may also include periodic inspection of such equipment as pipe, cable, connectors, solar array panel elements, and antennas.

Another crucial role of mobile robots will be to help maintain the central *Space Station Simulation* model described in Chapter 2. Built in stages from the early CAD/CAM database, the simulator will by 2010 be an accurate, real-time representation of the entire infrastructure, down to the smallest piece. It will allow pre-test simulations of proposed changes, and will spend part of the time searching for failure modes through "what if" scenarios.

Mobile robots will be dispatched to verify each failure mode uncovered by the simulation. In this way, inspection will not only be routine and automatic, but thorough and imaginative as well.

Among the technology requirements for the 2010 scenario are

- Advanced inspection sensors and sensor data fusion.
- Adaptive control systems for coordination of multiple telerobots.
- End effectors with micro-motion and micro-manipulation capability, and automatic reconfiguration by module interchange.
- Expert systems for decision support and analysis, simulation, failure mode search, and repair sequencing and planning.

3.2.3 Satellite Servicing and Repair Scenarios

Vehicles such as the OMV and orbit transfer vehicle (OTV) will come to be among the most valued tools in the Space Station. Perhaps 80% of projected Space Station activities involve vehicle servicing, including satellite maintenance and repair, retirement and exchange of devices in orbit, refurbishment, resupply, and refueling.

Much of the OMV workload will be scheduled tasks such as the weekly resupply of a co-orbiting materials processing platform, or the bimonthly refueling of a large satellite. Some tasks will be of a more spontaneous nature. The following scenario describes a typical example.

IOC Satellite Servicing Scenario

A low-altitude reconnaissance satellite has a malfunctioning magnetic stabilizer and is running low on fuel. Calculations reveal that the early model OMV could handle the problem. The basic idea is for an operator in the Space Station to use the OMV manipulator system to capture the satellite and return it to the Space Station for servicing.

The OMV had just returned from another experiment platform and was refueling itself when it received the word to attach the arms and end effectors required for a satellite capture. A number of remote controlled thruster packs are also stored on the OMV for later use in stabilizing the satellite's tumble. (Some EVA astronaut assistance may be necessary this soon after IOC.) After replenishing itself, the OMV requests a clear departure corridor and detaches itself from the Space Station. Once clear, it begins a series of rocket burns to alter its orbit.

As the OMV approaches the satellite, the remote operator orders a station-keeping minimum separation of 50 meters. The astronaut then commands OMV sensors such as radar and laser scanners to define the satellite tumble mathematically. Simulation by the Space Station computer indicates that as many as three passes might be possible (based on reserve fuel). This gives the operator twelve-second grip windows. It is determined that any other approach at capturing the satellite would damage the OMV's manipulators.

The Space Station computer programs the OMV thruster system for the first approach. The operator activates the master manipulators, switches on the necessary lights and vision systems, and removes a thruster pack from its storage location. Through vision, force feedback, and tactile sensing, the remote operator is able to quickly attach the thruster pack to one of the satellite's hard points. Subsequent passes of the OMV allow for the attachment of more thruster packs. Once this is accomplished, computer controlled commands are sent to the packs to stabilize the satellite's tumble. Next, the OMV manipulators, under control of the remote operator remove and restore the packs. The satellite is then grappled and returned to the Space Station. On return, Space Station beacons and passive systems guide the OMV to a satellite-repair work station where it can dock.

A small, mobile manipulator on the Station moves into position automatically, and an operator is summoned to attach the satellite to a fixture. The OMV is released to return automatically to its storage and refueling bay. Once there, it will automatically attach connectors for power, communications, and refueling. It puts special tooling or end effectors in their proper storage bins and waits for its next mission.

Meanwhile, the small telerobots and fixtures in the satellite repair work station begin the initial visual inspection. Assessment of exterior damage detects no leaking fuel. The remote operator specifies and supervises removal of fasteners and, finally, the access panels themselves. The operator then compares the view from the camera to the satellite's CAD/CAM data sent to the Station computer only a few hours before. There seems to be no physical damage to the system. Unable to determine the problem via telemetry, the ground station asks for an opportunity to attach the satellite computer to the Space Station computer. Following diagnosis, the operator will prepare the satellite for tethered storage. There it will wait for the necessary parts to arrive from Earth.

This scenario requires development of the following technologies:

- Automated rendezvous and docking.
- Telepresence interfaces for the OMV telerobot with visual display, force feedback, and tactile sensing.
- Dexterous manipulators and end effectors.
- Limited voice control of the telerobot.
- Automated refueling.
- Simulation software for the planning of robot actions with time delay.
- CAD/CAM database for object modeling.
- Quick-change capability for tools and end effectors.
- Limited expert systems for diagnosis and repair.

Year 2000 Satellite Servicing Scenario

Interface between remote operators and either OMVs or mobile advanced RMS are on a much higher level. The heightened onboard intelligence in place by 2000 would allow sophisticated natural language commands, automated planning, and spatial reasoning. Machine vision plays a much larger role in controlling the vehicles and manipulators. The OMV and mobile RMS will need less supervision for common tasks such as attaching themselves to objects. The increased autonomy will be the result of improved ability to coordinate multiple arms, navigate, track, and plan.

New technologies needed include the following:

- Advanced natural language processing.

- Enhanced voice control for multiple speakers through increased vocabulary recognition.
- Improved robot perception.
- Coordination of multiple robot arms.

Year 2010 Satellite Servicing Scenario

Many more robots will be available for space work. Evolution of machine vision, expert systems, and multi-system coordination and planning will allow vehicles such as the OTV to operate in nearly complete autonomy. Robots will automatically perform diagnosis and prognosis for systems under repair as well as for themselves. This may mean that simple satellite or platform repairs could be performed on site, allowing the process to be completed in a single OMV trip. New classes of repair problems will be resolved through coordinated use of multiple robots.

Among the new technologies needed are

- Robot self-repair capability.
- Multi-robot system coordination and planning.
- Extended expert systems for self-diagnosis and repair.

3.2.4 Manufacturing Scenarios

In the near term, space manufacturing will take two forms: simple reprocessing of Earth-provided materials using micro-gravity, e.g., pharmaceuticals and crystals, and repair and fabrication of parts needed on site. In the long term, the special attributes of space will attract more advanced industrial activities.

The near vacuum of space facilitates the use of electron-beam lithography, electron-beam welding, and ion-beam implantation. Lack of contaminants may enhance the direct production of circuits. Free-fall conditions help in bio-organic separation processes, deposition of uniform thin films, and elimination of contamination from container walls through the use of acoustic positioning. A fully automated and isolated space manufacturing unit would avoid contamination from humans and surroundings, eliminate mechanical vibrations, and protect against accidental emissions of toxic chemicals and bio-organisms. Tethered or co-orbiting platforms may be required.

The above-mentioned products use expensive materials and have a high market value for their size and mass. Their high value will likely justify the expense of space manufacturing and testing. With time, however, decreases in lift cost may make it profitable to produce items with lower value-to-mass ratios, and larger mass throughputs. The early station should not be so constrained as to forbid ambitious later endeavors.

The following technologies and components require development:

- A space-worthy, small load capacity telerobot, fitted with visual, tactile, and other sensors, and with interchangeable end effectors, having an extra degree of freedom for positioning along a rail.
- A telepresence interface for the telerobot, including voice control and visual and force feedback.
- A machine vision inspection system with integrated lighting, optics, microscopes, and micropositioning hardware.
- Special purpose hard-automated process modules.
- Limited expert systems for diagnosis and repair of modules.
- Standardized interfaces, languages, and processors.
- Special tools for repair, refurbishment, and production of other tools.

Year 2000 Manufacturing Scenario

The earlier system would be expanded and improved. The following new technologies would be necessary:

- Advanced telerobots for assembly operations, requiring the combining of information from visual, tactile, force, and torque sensors.

- More dexterous end effectors and interchangeable tools.
- Improved and extended vision systems to make telerobots more autonomous.
- Hard-automated process modules for additional stages of manufacturing such as packaging.

By this time, the ability to repair and fabricate some replacement parts will be crucial to Space Station operations.

Year 2010 Manufacturing Scenario

It should be possible to develop a fully automated manufacturing system capable of making sophisticated products. A candidate product might be a ***super-computer on a chip***, i.e., a powerful large-scale computer fabricated on a single slice of gallium arsenide, using electron-beam lithography. The ultra-pure crystals would also be grown in space. Such an ambitious goal would require development of

- Specialized process modules for the numerous stages.
- Cooperative manipulation of two robot arms.
- Extended expert systems to help plan, control, and monitor all operations.
- Significant increase in robot autonomy. It should be possible to program robots off-line using CAD/CAM databases and natural language to perform high-level manipulative tasks with minimum supervision.

This is, of course, a modest space industrialization scenario by some standards. Eventually, some of the possibilities discussed in Chapter 6 may lead to large-scale use of extraterrestrial resources. Such advanced automated forms as self-replicating units are not beyond our hypothetical reach in the 21st century. Again, such ventures should not be precluded, by unnecessary constraints built into the early Space Station.

3.3 TECHNOLOGY DEVELOPMENT AREAS

This section introduces important technology development areas for Space Station robotics. Accompanying reports prepared by ARP members (see appendix for this chapter) and contractors contain more detail than is presented here. Readers interested in a more thorough treatment should refer to those materials.

3.3.1 End Effectors and Mechanization

In present-day manipulators, the end effector is usually a parallel-jawed tong that allows crude grip movements. Three rotary motions of the terminal wrist combined with rectilinear movements of the supporting arm allow the hand to be aligned with an arbitrarily-oriented workpiece. Common hand tools such as wrenches, pliers, and hammers can be fitted with channeled pads that the tongs can grasp securely. In addition, the end-effector may be able to hold power-driven tools such as electric drills, rotary impact drivers, brushes, sanders, grinders, and needle scalers. The remote operator can guide and use them with direct "feeling" of contact, alignment, and reaction forces of tool and workpiece. The emphasis in these devices is clearly on versatility, simplicity, and adaptability to poorly-defined tasks in an unstructured environment.

Today's factory robots emphasize fast, precise, and reliable execution of a few repetitive tasks. Typically, they move well-defined parts, tools, or specialized devices through programmed motions in a highly structured environment. The end effectors, wrists, and arms are somewhat like those of the servo-driven portion of a manipulator or teleoperator. However, because of the emphasis on precise position control of the end effector, the structural and drive elements (for comparable load capacities) are generally massive and rigid to minimize deflections. Special spring-loaded or compliant end effectors or parts holders can often maintain contact forces within acceptable limits. Force measurements by sensors in end effectors, wrists, workpiece holders, or support tables are necessary to provide compensatory end effector displacement.

End Effectors

Parallel-jawed, spring operable end effectors with one-way closing drive allow the control of position and force in one direction only. One can increase the versatility of these simple devices in several ways: by making jaw faces remotely interchangeable to allow replacement of damaged devices or the insertion of ones suited to heavy work, and by changing tong tips or entire assemblies remotely to select types suited to different surfaces or having different opening or closing ranges.

A special purpose two-way drive end effector, power-driven in both the opening and closing directions, is mechanically more complex, but has significant advantages over the spring-opening type. In the latter case, (1) slight damage to the bearings may prevent the spring from opening the tong and, (2) significant effort is required to close the tong to contact a workpiece, even before any holding force is applied. The bidirectionally-powered drive can also be used (with contact faces on the *outer* sides of the jaws) to grasp hollow parts from the inside.

Telerobots used in the Space Station will require special end effectors with capabilities beyond the simple grasp function. For applications not requiring twist (or roll) motion, a special two degree-of-freedom end effector may be used to actuate a latch or produce other movements in the grasped workpiece. Sensor arrays on the tong jaw faces could detect area-distribution of contact forces (hence, part shape or form). Examples include slip sensors, tong tip contact sensors, and proximity sensors. End effectors may provide auxiliary power and communications capability to an auxiliary device.

Finally, end effectors with special, possibly computer-enhanced, sensory capability may be used for inspection or testing. Examples might be visual examination sensors with close-up television, microscope, or endoscope; radiation detector probes; scanning electron microscope probes; excited fluorescence probes; and surface mechanical impedance testers with variable-frequency vibratory excitation and response measurement.

Mechanization

The end effector, workpiece, or tool-holding platform may have fitted special-purpose devices such as jigs and fixtures, tools or parts holders, or adapters to simplify repetitive or complex fabrication or assembly operations. These devices may be passive, or power-driven by built-in actuators or by manipulator forces. They may even incorporate status or condition sensors, e.g., "out-of-parts," "ready," "out-of-limits," etc., and transducers, e.g., temperature, multi-axial force, multi-axial displacement, etc. A few examples are briefly presented below.

1. Storage racks or caddies for holding tools or fixtures in well defined locations and orientations to facilitate quick or programmable exchange.
2. Passive, compliant, end effector mounted workpiece holders to control assembly forces. Examples are commercially available remote-center-compliance devices for holding parts such as precision bearings or bushings. These accommodate significant angular and positional misalignment and allow insertion into close fitting holes with clearances of a few ten-thousandths of an inch, a task difficult for even skilled mechanics to accomplish without jamming or binding.
3. Similar instrumented remote center compliance devices with multi-axial transducers measuring angular and positional deflections (and, indirectly, forces), providing control information for automatic alignment correction.
4. Compliant work holder platforms performing functions similar to 2. They may also be fitted with breakaway devices that allow them to float when a pre-established force level is exceeded, preventing tool or part damage.
5. Instrumented compliant platforms similar in action to 3.
6. Multi-axial force and moment sensors interposed between wrist-joint and end effectors functioning similar to 3.

Spring-powered impact tools can deliver a controlled impulse (hammer blow) to the work. An adapter can convert this linear impulse to a rotary impulse that can tighten or loosen threaded fasteners. A modification of the linear tool with a terminal hook or shackle can provide a reverse-impulse to break loose and extract pin-type fasteners such as hairpins or cotter keys.

Repetitive or difficult operations such as crimping, forming, bending, and riveting may justify special purpose assembly and fabrication devices. Either built-in actuators can perform the operation or the robot's end effector can work directly. For operations such as rivet-heading, a mechanical impulse-generator might be more appropriate. This could be held by the end effector or built into the special device. In the latter case, the end effector would only have to provide the driving force, while the tool position is pre-established in the fixture.

3.3.2 Control Systems

Control systems govern telerobot activities and behavior, including maintenance and housekeeping. They must cope with operating environments that often involve a great deal of uncertainty. Other types of control systems will be needed for use in chemical processing, experimentation, and structural and attitude control. However, since control techniques for these applications are well-known, they will not be described further here, except as they relate to telerobots.

Control System Architecture

It appears natural to organize the control system as a hierarchical structure because lower-level functions are often repetitive, and because the tasks can usually be described hierarchically, as well. A particular telerobot, for example, could be described at a high level as installing modules, while at a lower level it is fetching a fastener, and at a still lower level it is controlling actuator voltages. In a hierarchical control scheme, high-level commands are decomposed until they become specific, time-phased instructions for actuators and sensors. Sensory information, on the other hand, is combined further up the hierarchy into symbolic descriptions. There is extensive interaction between control levels.

A hierarchical decomposition might involve the following levels:

- Central Control Station.
- Agent.
- Task.
- Process.
- Coordination.
- Axis and Detection.

These control levels do not necessarily have well-defined boundaries. Each involves both control and perceptual functions.

The *central control station* supervises several telerobots. It handles communications and operator interfaces (including speech control, displays, and force-reflecting master controls). It also provides interactive task planning aids and models of vehicle capabilities and configurations. Furthermore, it can access databases describing the entire Space Station and environment. From the station, operators can control telerobots directly or supervise nearly autonomous activity. As system capabilities evolve, the control station computers will do more of the overall task coordination and verification.

The *agent level* is an extension of the telerobot's on board control station. It handles communications and oversees dedicated activities such as startup and shutdown. It has access to information from all onboard control levels.

The *task level* is subordinate to the control station. It performs task activity planning and monitoring, and high-level perception such as situation assessment and recognition. It also allocates resources in response to the task, robot status and external situations and then initiates execution. Multiple subtasks may be active simultaneously. If the task level encounters situations it cannot handle, it notifies the control station. This level requires extensive symbolic processing. At IOC the task level will not be sophisticated, but its intelligence will increase with time.

The *process level* is lower still. It executes and monitors well-defined processes in known situations (such as installing snap-action girder fittings, and normal, obstacle-free docking) that can rely on simple geometrical perception and do not require a great deal of reasoning. Multiple processes can be active simultaneously. The process level can handle benign anomalies as reflex actions, but more severe problems require intervention from the task level. Process-level commands are decomposed into coordination-level commands and sent downward. Process-level capabilities will be fairly well-developed by IOC although space applications will require some testing.

The *coordination level* is subordinate to the process level. It coordinates and monitors vehicle actuators and sensors in several modes, such as position-force, stiffness, and velocity control, using information derived from perceptual processes. It takes account of kinematic and dynamic interactions. Sensor information fusion begins at this level, and is used to construct and maintain a stabilized low-level world model.

The *axis and detection level* is the bottom-most decision realm. It includes axis control in the servomechanism, sensing, signal processing, and feature extraction. Multiple sensing modes, including multispectral stereo vision, tactile, radio frequency, proximity and force, structural stress, axis position, velocity, and torque, might be included. An inertial reference unit is important as well. After closing the necessary low-level loops, the sensor data is processed and passed to the coordination level which uses it in world model construction and maintenance as described above.

Control System Evolution

In the near term, humans will handle most of the difficult cognitive processing, such as allocating resources, finding an object of interest in a cluttered scene, or responding to significant failures. The control system will coordinate axes autonomously and deal with well-defined and repetitive situations once humans have specified procedures and objects of interest.

By the year 2000, improvements in computing, machine perception, planning, and reasoning should allow telerobots to operate more autonomously and require less operator intervention. One would expect, for example, the systems to be able to recognize objects close to defined positions, plan paths automatically, and avoid obstacles.

Capabilities past the year 2010 are extremely difficult to predict. Still, it does not seem unreasonable to project that telerobots of that era will be able to perform many autonomous activities, such as cooperating with one another, assessing situations, and allocating resources optimally. They might be able to deal autonomously with significant error conditions that require recognizing distorted components and generating plans based upon functional needs (such as removing a blockage to clear an exit path) in real time. In this time frame, telerobots will require only minimal human intervention to perform their normal tasks.

3.3.3 Telepresence and Human Factors in Telerobotics

The term *telepresence* describes advanced telerobots with a high degree of integration between man and machine. For remote work this may require providing a quantity and quality of sensory feedback sufficient to approximate actual presence at the worksite. This will be a critical transition technology until robot autonomy is achieved.

In the IOC version of the Space Station, optimal telepresence will be essential to the effectiveness of remote manipulators. In addition to realism, the telerobot control station must provide interactive facilities that are efficient, comfortable, and do not lead to undue fatigue.

By IOC, it is possible to develop a telepresence system with the following major characteristics:

- Stereoptic color vision system, slaved to operator head motion.
- Head-mounted vision display.
- Paired 7-degree-of-freedom manipulator arms with force control.
- Force-indicating hand controllers or exoskeleton arms for control.

- Two grapple arms or one docking device.
- Interchangeable end effectors.

Sensory Technologies for Telepresence

Sensory technologies for the man-machine interface are essential to IOC telepresence capabilities. The following paragraphs discuss critical technology issues that must be addressed to meet initial needs and those beyond IOC.

Stereoptic vision provides the operator with depth perception, often critical to successful task performance. One approach to providing it may be mounting the principal stereo cameras on a platform with at least two degrees of freedom (tilt and pan). Because the operator's hands will be busy, the camera platform should be controlled by head motions, voice, or both. Computer control of the cameras to track the end effectors is also a desirable option. Other remote cameras should provide oblique and closeup views of the worksite. Color offers additional cues that aid in scene recognition and understanding, particularly in the unusual lighting conditions of space.

If the work-site cameras are controlled by the operator's head motions, then a head-mounted display is also desirable. A binocular display, for instance, works by providing a separate view for each eye. The display system should allow superposition of computer-graphic information, e.g., a heads-up display.

New display techniques will play a major role in allowing efficient telerobotics under conditions of noticeable time delays, such as when an Earth-based operator controls an experiment in geosynchronous orbit. Predictive displays will let the human operator see the effects of manipulator commands without delay. By IOC, the predictive and preview display could be a model-derived line drawing superimposed on the actual video image. In later systems, the predictive display could be an accurate computer generated image of a three-dimensional model of the manipulator's environment including high-resolution, real-time, shaded, and stereoscopic images. An automatic vision system could compare delayed returning images with the predictive displays and alert the operator to differences.

When the work is performed in a visually confusing or disorienting environment, (e.g., if the manipulator and work object are rotating, moving shadows could be distracting), a model-based display could represent the situation in a stable coordinate system and eliminate extraneous motion.

Visual fatigue may reduce productivity even in highly motivated station operators. All the worries about posture and lighting ergonomics apply here; in addition, the harsh visual environment of space prevents the beneficial effect of visual relaxation by viewing a distant natural scene. This is an area deserving of human factors study.

Information from tactile and other force sensors on the manipulator should be conveyed to the operator. Many current teleoperator systems accept force as an operator command, and lower-level servo loops direct the manipulator to exert that force. In the absence of time delay, this loop should be extended to provide force-feedback to the human operator.

Where there *are* time delays, predictive force feedback based on a dynamic model of the manipulator's environment will be useful to improve on the low productivity of move-and-wait tactics.

Computers in the manipulator supervisory control loops can assist with accurate sensing of the manipulator positions. Slip sensors are also useful to indicate when manipulators are losing their grip on objects. In general, force, torque, and position-sensing abilities appear necessary in a near-term telepresence system.

For telepresence systems beyond IOC, advanced contact sensors can give the operator detailed information on shape, compliance, slip, and contact forces at the worksite. Transformations of some sensory information may convert measurable inputs into other forms, e.g., texture into sound. Different operators would tune the telepresence system to suit their preferences.

Voice Recognition Control

Voice recognition is a current technology that is beginning to be applied in telerobotics. It will help increase the flow of information from human to machine without interfering with hand-controlled operations. Current applications of voice control include camera pointing and programming of set points to which the manipulator(s) and camera can be directed with a voice command. These applications are ideal for IOC because current technology can easily support their limited vocabulary requirements and the Space Station's small user population.

As supervisory control and then autonomous operation are realized, voice recognition and improved natural language understanding will allow the operator to communicate with higher parts of the hierarchical pyramid, opening the utmost flexibility in controlling remote operations. The supervisory control computers will be able to respond conversationally to the operator during teleoperated activities.

3.3.4 Perception

Perception is defined here as the translation of characteristic or relational object properties into the information required to perform a robot function. The properties can be geometric, mechanical, optical, thermal, acoustic, magnetic, radioactive, or chemical in nature. They are used to form a hierarchy of symbolic representations constituting knowledge about the state of the world associated with a given task at a particular time. Perception is critical to manipulation, in that the manipulator system must perceive the relationship between itself and its physical environment.

Perception is usually divided into two categories: noncontact sensing and contact sensing. Noncontact sensing refers to information-bearing signals generated by transducers that are not in physical contact with the object being sensed. There have been some notable advances in noncontact sensing, especially in the area of computer vision. A typical system involves a television camera interfaced to a computer that analyzes the scene being viewed. These systems may be used to inspect, count, orient, or locate parts and to guide the actions of manipulators. Currently available computer vision systems are inadequate for many planned robotic applications in space, due to the harsh lighting conditions and the unstructured nature of the workplaces. Other noncontact sensing techniques use other types of processes such as radar, sonar, or thermal emission.

Future Space Station robotic applications would be aided by a vigorous program of technology advancement in sensors. A critical area is the improvement of visual, tactile, and range transducers.

As the name suggests, contact sensing involves transducers that are in physical contact with the object whose properties are being measured. Contact sensing systems usually involve touch, force, slip, and pressure signals. Systems that perceive these types of signals are crucial to dexterous manipulation. The use of touch and force feedback can result in extremely high precision movements, even with an imprecise manipulator.

Touch or tactile sensing involves the measurement of very small forces at several points on the robot hand. Switches, piezoelectric devices, pressure sensitive plastics, and strain gauges may be used. At present, there are no adequate tactile sensor arrays, and the interpretation of tactile images is in its infancy. Tactile analysis will provide valuable information about the exact location, shape, and identity of parts in robotic applications. Force sensing provides information about the net force and torque acting on a manipulator hand. Forces can be measured by equipping a manipulator with a special wrist that has strain gauges or piezoelectric sensors. Force sensing is critical to precision position measurement since it allows small deviations to be translated into large forces that are easy to measure. A major area of research involves the development of methods for the fusion of data from a variety of sensors, especially visual and tactile.

3.3.5 Manipulation in Space

Virtually every manipulation task performed on Earth involves gravity. Screws can be rested in a hole in preparation for driving, objects will remain at rest because of gravity-generated friction, objects can be pushed and slid tangentially to horizontal surfaces, and mating surfaces can be brought together with little guidance using gravity-generated forces. Workers can apply torques by bracing themselves against the earth.

None of these familiar conditions need hold in space. The body forces can even vary continuously. This has two major consequences. One is that we will have to find substitutes for the steady force field normally provided by gravity. The other is that we will have to develop a branch of the *science of manipulation* that allows for variable acceleration vectors.

A related consideration is that Earth-based manipulation is limited to objects that can be lifted by a manipulator, or supported by air-pads, flotation, rafters, or balancing devices. In free fall, objects of great inertial mass can be manipulated because they are weightless. However, their acceleration is limited by the available manipulator force. More important, the relative velocities of interacting bodies must be limited to control contact forces during manipulation, assembly, or docking. Deceleration with maximum available force requires a finite distance to reduce relative velocity to zero to avoid uncontrolled (and possibly catastrophic) momentum on contact. As a result, there is a pressing need to develop predictive controls and displays. Control techniques that involve modeling of payload masses and prediction of their responses will be extremely important.

Researchers need to consider gravity *explicitly* for both terrestrial and space applications. This will result in a more fundamental understanding of manipulation in general.

Research efforts must be initiated in the following areas pertaining to manipulation in the variable-gravity environment:

- Development of a science of manipulation, independent of specific manipulator design or control.
- Specialized tactics for the variable acceleration environment.
- Actuator improvements (many implications for the entire field of robotics).
- Manipulator design.

3.3.6 Operation Planning and Databases

A hybrid system with both robot and teleoperator features can be a major tool with a long lifetime in the Space Station. As such systems become more autonomous, they will be able to perform more tasks, thus saving time for the human operator, one of the most valuable and costly resources on the Space Station. Key to the development of even low levels of autonomy will be CAD/CAM databases containing detailed descriptions of all components of the Space Station itself, everything within it, and every external object that the telerobot might encounter. Planning algorithms will be necessary to use the databases to generate programs for telerobot operation. A few simple examples will illustrate the areas requiring technology advancement.

The telerobot will perform materials handling chores that are hazardous, unpleasant, or inconvenient for people to do. Initially, this will be done via directly human-controlled teleoperation. Later, astronauts will be able to issue simple high-level commands to the robot. "Robot, push button A on panel X (perhaps located on a normally uninhabited module)." "Robot, turn dial B on panel X 10 degrees counterclockwise." "Robot, pick up container C and put it in storage bin Y." The human operator may have previously guided the telerobot to the vicinity of container C or panel X so that it does not have to search a wide area. A telerobot that can follow such simple commands can perform many useful housekeeping and experiment-management chores. With a suitable supervisory control system, any malfunction or uncertainty can interrupt the robotic activity, raise an alarm, and allow a human operator to take over.

Responding to such commands requires several levels of CAD/CAM-driven planning algorithms. At the top, a task-planning system will divide the task into simpler subtasks for which telerobot program segments can be generated automatically, based on information derived from the CAD/CAM database and on sensor inputs. For example, the command to push button A, would result in the generation of a program segment to make the telerobot scan the surrounding area with its vision system until it recognizes panel X. Next, a program segment would be generated to determine the relative position of the panel. From the database description of panel X, the precise location of button A can be determined. It is then a simple matter to generate the program segment to make the robot move to the button and push it.

Putting container C in storage bin Y involves computing from its database description a position for gripping the container. The next program segment would direct the robot to grasp the container. If the database contains descriptions of the storage bin and its location, a path to its vicinity can be computed. Program segments can be generated to make the telerobot move to the bin and place the container in it.

Generating robot program segments from database information is not simple, but is feasible during early Space Station operation with a modest research effort. The generation of program segments to make the telerobot move to the vicinity of the storage bin requires the development of path planning and obstacle avoidance algorithms. Also important is the development of a world model containing a description of every object in the domain of robot activity. This model must be updated frequently with information extracted from the robot's sensors. Potentially the most complicated part of the operation is the generation of the program segment to place the container in the storage bin. In a weightless environment, bins will probably be closed. The telerobot therefore must recognize that the bin is closed, realize that it must open the bin, plan how to open it, and then close it again after depositing the container.

A more complicated task would be simple repair by module replacement. "Robot, replace module D in device Z." Either via teleoperation or the inverse of the storage operation described above, the telerobot would arrive at device Z with the replacement module. Next, the telerobot must figure out how to remove the old module and replace it with the new one. In general, this is a very difficult problem. However, if the device were designed with automatic repair in mind, only relatively simple operations would be required, e.g., removing an access barrier of some kind, pulling the old module out, and pushing in a new one. Given the ability to remove and insert the modules, the planning issues reduce to determining where the objects are with respect to the robot. This problem can be solved by using information from sensors and the CAD/CAM database similar to that described above. Of course, there are also complex joint motion and contact force control problems to be solved.

While many of the individual capabilities required in the above scenarios exist, research is needed on several planning issues before the operations become feasible. A major challenge is to develop general ways for dividing programs into segments that can handle a broad range of situations. This requires investigation of the following problems:

- Task planning.
- World modeling.
- Motion planning.
- Knowledge representation.

Task planning research is needed to address the general problem of generating an adequate sequence of subtasks. It will involve expert systems and other artificial intelligence work. *World modeling* will address questions of how to acquire and represent information on the physical status of all points in the robot's work area. The world model will be used during robot operation to modify its planned behavior. Knowledge of how the robot is constructed will also be used.

Motion planning occurs at two levels, gross and fine. The distinction is generally more one of technique than principle. Gross motion planning typically involves determination of interference-free paths for a robot from one point to another. In fine motion, it is necessary to determine motion constraints and, perhaps, force or torque constraints among the objects to be manipulated. These constraints will influence program strategies for achieving the desired motions. The planned motions also require run-time strategies for obstacle avoidance and joint motion and contact force control; significant technology advancement is needed in these areas.

The principal issues in *knowledge representation* concern what information needs to be kept and how it should be represented and related to information typically kept in CAD/CAM databases.

The hybrid operation provides an ideal experimental domain for this advancement. Operations can be performed via teleoperation, initially. As autonomous capabilities are developed, they can be integrated into the system naturally, with the human operator providing high level intelligence and intervention in case of uncertainty or malfunction.

3.3.7 Maintenance of A&R Hardware

Self-calibration, or built-in auto-calibration, will be an essential feature of many automatic devices, control systems, robots, and teleoperators aboard the Space Station in the 1992 time frame. As an example, telerobots performing manufacturing or experimentation should have a reference home or base coordinate fixture in their work envelope. They would be programmed to go to the home position periodically. During this operational sequence, their joint encoders would be measured and recorded. The design of the home position fixture and the end effector would enable absolute accuracy of initial calibration. They would also, through use of instrumented-compliance features, enable the robot to return to the exact home position. This second set of encoder values would also be measured and recorded.

A comparison would next be made between the observed encoder values and the base assigned limits. Diagnostics could then discriminate between a possible mechanical or kinematic defect, or a dynamic control defect, should the inaccuracy be beyond pre-established limits. An astronaut would be informed of the problem and would question the computer to isolate it further. The astronaut would then decide whether to perform repairs.

In the year 2000 time frame, sufficient diagnostic data would be gathered and analyzed to allow long-term failure-mode prognosis based on well understood degradation of measured diagnostic parameters. The computer would detect these trends well in advance of failure and would inform the astronaut of mean time to failure and machine status. This feature would be of great value in critically designed machines such as large telerobots that may be occasionally subjected to overloads, excessive speeds, or unusual conditions. Such maintenance could greatly extend machine life.

By the year 2010, robots would be capable of diagnosis, prognosis, and a degree of automated self-maintenance. The astronauts' interface to the automation would be at a high, mission-oriented level and could include many extraordinary machine performance requirements. Any harmful operations would be performed within the limits of recuperation afforded by automated servicing, maintenance, or replacement of basic components. This intelligent extension of machine performance beyond continuous-duty, full-endurance parameters will be made possible by an expert system embedded in the machine controls. It would contain a knowledge domain of wear, fatigue, and yield strength values for all critical machine components.

Robots would maintain and repair themselves, other robots, and other automated equipment. This would require modular construction extending from the arm structure itself to the motors, resolvers, electronic drivers, and onboard computer systems. Besides permitting easier servicing, the diagnostic functions would then become much more specific in defining the device's fault and cause relationships.

To achieve the desired level of self-calibration, diagnosis, prognosis, and repair, research will be necessary in the following technological areas:

- Expert systems.
- Harmful effects of the space environment.
- Fatigue and wear rate information in the space environment.
- Automated servicing, maintenance, and repair of automation elements.
- Diagnostic sensor technology.

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- Fatigue and wear rate information in the space environment.
- Automated servicing, maintenance, and repair of automation elements.
- Diagnostic sensor technology.

3.4 IN CLOSING

This chapter has addressed the major robotics technology areas deemed by the Panel as critical to the Space Station. Progress in many of these areas will hinge on advances in *computer science* and *knowledge engineering*. The following chapter covers those technologies.

Chapter 4

COMPUTER SCIENCE AND KNOWLEDGE ENGINEERING

4.0 SUMMARY

New developments in computers, networks, databases, and artificial intelligence can make the Space Station more capable and less expensive to operate by

- Automating basic operations, thus reducing crew involvement and providing more consistent operation over long periods of time.
- Simplifying and automating the development and maintenance of onboard computer-based systems.
- Allowing large onboard databases with intelligent user interfaces. (These can result in greater Space Station autonomy, more automatic operation, and more extensive onboard manufacturing, training, and staging facilities.)
- Making the Station easier to modify, expand, maintain, and repair.
- Providing onboard expert systems to handle many routine tasks and reduce the Station's dependence on ground support and communications.

Current technology in *computer systems* has the following major limitations:

- Insufficient fault tolerance and inability to allow expansion and modification.
- Lack of standardization of computer languages and networking methods.
- User interfaces that cannot take advantage of or adapt to varied skill levels, and which do not explain their actions.
- Lack of adequate languages and development tools for real-time systems.
- Long lead-time for space qualification of hardware.

Current technology in *knowledge based and expert systems* has the following major limitations:

- Difficulty of defining and collecting knowledge.
- Slow execution.
- Lack of development tools and standards to codify and represent knowledge.
- Lack of tools for checking, verifying, and validating systems.
- Inability to effectively represent uncertainty and missing knowledge.
- Inadequate links between symbolic computational facilities and real-time or numerical systems.

NASA should emphasize technology advancement in the following areas:

- **Expandable, fault-tolerant, and secure hierarchical computer networks.**
- **Effects of radiation, vacuum, and low gravity on computing elements.**
- **Man-machine and man-computer interfaces for use in space.**
- **Small, specialized computers as hosts for limited-purpose expert systems.**
- **Modifiable and extensible expert systems capable of handling uncertainty.**
- **Verification of expert systems.**
- **Integration of expert systems and symbolic computing with real-time control and data acquisition and with numerical computation.**

Vigorous and sustained activity will be necessary in order to bring about these advances. Exhibit H shows suggested categories (divided into areas in which NASA should *lead, leverage,* or *exploit*). The Delta column is the difference between the recommended *baseline* and *minimal* funding levels. The Fallback Order is the sequence in which categories might be reduced or dropped (lowest numbers first), in case of cut-

backs, and result in the least harm to a high-quality program. Each category appears only in the most important applicable division; for example, we assume that NASA should also apply *leverage* or *exploit* developments in areas in which it must *lead*.

Exhibit H

A&R Technology Program: Information Management

	Category	Baseline Program ($M/year)		Minimal Program $M/year)		Delta $M/year	Fallback Order
		Research	Demos	Research	Demos		
NASA must *lead*	Exp. Sys. Mission & Payload Control, Planning, & Directing	5	1	2	-	4	8
	"Smart" Simulations	8	2	5	1	4	8
	Fault-Tol., Reliable S/W Tools	6	1	4	-	3	7
	CAE Standards	2	-	1	-	1	5
	S/W Language Standards	2	-	1	-	1	5
	Auto. Design-For/Integr. Techn	3	-	2	-	1	3
NASA applies *leverage*	Space-Related Custom H/W	1	-	-	-	1	8
	Communications Networks	7	1	5	1	2	8
	Large-Scale Databases	5	1	4	-	2	8
	Knowledge-Based System Dev	8	2	5	1	4	8
	Sensing Algorithms*						
	CAD-Directed Programming	3	1	2	-	2	6
	Real-Time Exp. Systems	2	-	1	-	1	4
	Facility "Seed" Funding	5	-	2	-	3	2
NASA can *exploit*†	Computer Architecture & Chip Technologies	3	-	2	-	1	1
	Speech Technologies	1	-	1	-	-	-

* Money applied in Man/Machine Sensors/Integration.

† Examples only.

The Space Station's control and information management system incorporates most of the requirements that motivated the Japanese Fifth Generation Computing Project. It has a similar time schedule and promises similar spinoffs for the general economy. A major advantage of the Space Station project, however, is that it has a specific aim and is therefore less likely to suffer from a lack of practicality, overall direction, or visible progress.

4.1 CRITERIA AND RECOMMENDATIONS

This chapter focuses on Space Station developments needed in the areas of computers, networking, database management, and expert (knowledge-based) systems. The fundamental aim here is to create and sustain a state-of-the-art control and information management system in the Space Station.

4.1.1 Criteria

We may divide our underlying criteria in this chapter into design principles and operating methods. The *design principles* we intend to promote are

- Allowance for continued growth and reserve capacity in computing power, network capacity, database storage, and high-speed communications.
- Allowance for ever-increasing automation, leading toward eventual reduction of human involvement in routine functions.
- Standardization and restriction of the number of computer languages, interfaces, networking methods, and database formats.
- Requirement of fault tolerance and spaceworthiness.
- Use of state-of-the-art hardware, software, and methodologies to the limits allowed by more efficient space qualification standards.

The *operating methods* we intend to promote are

- Ever-increasing autonomy of the Space Station from ground control.
- Simplification and automation of mission and payload planning and control.
- Allowance for periods of crewless operation of the Space Station.
- Allowance for monitoring, direction, and control of the Space Station from ground operations, if necessary.

4.1.2 Principal Short-Term Recommendations

The following are important short-term goals in the area of information systems:

- *Develop a secure information system architecture* with centralized control, distributed processing power, fault tolerance, reserve capacity, and extensive expandability. The system should link all computers in the Space Station.
- *Develop a standardized network interface and protocol* that allows for expansion, high data rates, and media independence.
- *Select a restricted set of high-level languages* on the basis of functionality, portability, standardization, and conformity with modern software engineering principles. There should be only one language used for general operations and one for knowledge engineering. Special languages required for database management, simulation, robotics, etc., as well as simplified user interface dialects and program design languages, should incorporate routines for translation into these basic languages.
- *Attempt to develop knowledge databases and advisory expert systems* in the areas of planning and scheduling, mission and operational control functions, environmental monitoring, power distribution monitoring, equipment diagnosis and repair, communications, health maintenance, and inventory.
- *Develop an onboard interactive workstation* with symbolic programming capabilities and a graphical user interface for: running expert systems, training and briefing, scheduling and planning, and information retrieval and management.
- *Start developing an integrated Space Station database* to include computer aided design and computer aided manufacturing (CAD/CAM) parts and system models, operating methods, and programs for robots.
- *Establish a central NASA laboratory for knowledge engineering.* This should provide large-scale symbolic computational power and simulation facilities, software tools, program and knowledge libraries, and standard interfaces for connections to real and simulated equipment. It should allow for the definition, collection, and representation of knowledge for use in expert systems and other applications. The laboratory should also serve as the focus for training and for demonstrations aimed at showing project managers practical applications of knowledge-based systems.
- *Form knowledge-based application teams* to verify, validate, update, and extend knowledge-based applications for Space Station sub-systems. Each team should consist of a knowledge engineer, a subsystem expert, and an astronaut.
- *Investigate data storage and transfer methods* for representing, storing and accessing the large amounts of data required for information management, both onboard and on the ground, as well as methods for secure data transfer.

4.1.3 Principal Long-Term Recommendations

The following are more ambitious, long-term goals:

- Move from advisory expert systems to actual control of selected major functions.
- Move from heuristic, rule-based expert systems toward model and reasoning-based systems that include: common sense reasoning, extensibility, self-learning, and methodologies for making constrained decisions when available knowledge is incomplete or uncertain.
- Develop expert systems for more general applications such as navigation, surveillance, construction, manufacturing, satellite repair, and crisis management.
- Upgrade onboard workstations to allow extension, modification, reprogramming, verification, and validation of expert systems.
- Extend onboard simulation capabilities.

- Extend the NASA knowledge engineering facility to include simulation, verification and validation, and checkout.
- Integrate expert systems for unified information and control.
- Develop standards for the specification of knowledge as part of the documentation of all subsystems.
- Develop methods and standards for automatic logging of events such as repairs, maintenance, and manufacturing operations for use in CAD/CAM and knowledge databases.
- Move databases to onboard storage with ground backup.
- Develop standards for security and privacy of databases and communications.

4.2 THE OVERALL COMPUTER SYSTEM

The overall Space Station computer system must allow for incremental growth, provide reserve capacity, offer fault tolerance, and permit hardware and software changes without extensive redesign or reconfiguration. It should use a limited set of standard languages and network interfaces, and provide easily maintainable hardware and software.

4.2.1 Overall Architecture

The overall architecture must provide for modular growth, fault tolerance, maintenance of critical central functions, high-speed signal and symbolic processing, real-time operation of subsystems, and access to large amounts of on-line and ground-based storage. The requirement for modular growth means that the system must be largely distributed, allowing the addition of new computing units without taxing the capacity of a central system. The way in which the Space Station is to be assembled from modules dictates that the system must grow unit by unit. On the other hand, there must be a main control unit, with built-in redundancy, to provide overall direction and keep subsystems from conflicting with each other or interfering with vital functions.

The overall system may well have a hierarchical structure similar to the human nervous system. Elements would range from simple sensors and actuators at the periphery, to the main control unit. Technological advances will surely allow ever more powerful machines in space. While the Initial Operational Capability (IOC) computing elements may be largely dedicated microprocessors and minicomputers, later units may be the equivalent of today's supercomputers or experimental parallel processors.

Certain issues here require further study; there are two questions of special importance:

- Should the IOC system include a central machine with much greater capabilities than any of the others? This could be a miniaturized version of a modern mainframe. The alternative would be to use only specialized minicomputers with optimized firmware.
- How will the onboard system provide the large amounts of on-line storage required? Hard disk units are bulky and delicate, current videodisks are not writable, and solid state bulk storage is still in the experimental stage.

Developments in computer architecture, hardware, operating systems, and mass storage devices are proceeding rapidly. New very large scale integration (VLSI) chips may incorporate many complex control, simulation, and CAD/CAM operations, thereby greatly increasing the speed and reliability of specialized small computers. Flexible operating systems for supercomputers may soon enable them to operate like high-speed versions of today's multi-purpose minicomputers. Moreover, new non-von Neumann architectures featuring massive parallelism and different processing concepts, (such as data flow) are under intensive development. Finally, several new mass storage architectures (user-shared, distributed function, etc.) have appeared with up to terabyte capacities and gigabit per second transfer rates. The best approach may be to allow as much time as possible for these developments to mature before making final hardware decisions.

We should note that the automation and robotics programs outlined by the contractors all assume an expanding network of relatively small, specialized machines. This could create several problems, including unreliable elements, conflict resolution between elements, safeguarding vital functions, and achieving a final integration of unprecedented complexity. The architecture should be able to incorporate new machines, while retaining the system's security and fault tolerance. Thus, the main control module should monitor all system elements and take action when it discovers aberrant behavior.

There should also be an Earth-based computer development system capable of functioning as a backup for the onboard system through a high capacity communications link. The system should also allow backup control and status reporting through the ground link. This would permit ground-based personnel to monitor and control operations directly if no crew were present, or under emergency conditions.

The Los Alamos experience, discussed in Appendix 4-A, favors distributed processing along with centralized and redundant control. A hierarchical design will allow an initially centralized system to change over into a highly distributed one as the Space Station evolves. This will avoid both obsolescence in the IOC and expensive retrofitting. Designing the system to decentralize further in time will allow more functionality, higher performance, and greater reliability.

Special care must be exercised in system development to provide a high degree of fault tolerance for the main control and other critical functions. Failure anywhere in the hierarchical system, even at the top, must not affect essential operations.

Evolution of the Space Station will require both an expansion of the overall computer system and the development of more powerful subsystems. Improved communications, more capable specialized peripheral processors, and intelligent robots and sensors will all be necessary as the Space Station grows in size and functions. It is of primary importance to emphasize this networking aspect of the design from the outset.

4.2.2 Designing for Growth

The key ~~to~~ designing for growth is to make the computing and communications software as hardware-independent as possible. The ideal approach would be to specify the system tasks and software first, delaying the selection of hardware as long as possible. In practice, however, the hardware's physical and electrical characteristics must be determined early in the design process to allow allocation of space, cabling, and power. This still allows upgrading later if the software uses portable, standardized high-level languages, and if the system features standard, expandable interfaces. During the past decade, technological advances typically have resulted in more powerful computers with no increase in space or power requirements.

Other factors that allow for growth include

- Reserve network bandwidth, computing power, and database storage capacity.
- Self-configuring systems software, in which the operating system automatically determines the current system resources and reconfigures itself appropriately.
- Modules that are self-identifying by name and function.
- Onboard development, test, and simulation facilities.
- Secure fault-tolerant systems that protect existing computing elements from interference when new elements are added.

4.2.3 Computing Elements

Initially, most onboard computers will probably be traditional single-processor von Neumann machines. Later, however, the network may include parallel machines, specialized units, and peripheral processors of various types. While such machines are now in use, practical experience with them is limited and little systems software exists. Not much is known about making them fault-tolerant, and adequate tools for development and evaluation are not yet available.

One way to achieve greater computing power eventually is through the use of specialized hardware units aimed at specific classes of problems. For example, array processors outperform comparably priced general purpose computers by factors of 10 to 100 on such tasks as Fourier transforms and finite element analysis. A typical application on the Space Station might be the control of autonomous vehicles, where specialized machines could handle cognitive functions, control, and communications. Appendix 4-B describes a comparable application involving a submersible robot vehicle.

A specialized machine requires a definition of the nodes and processing elements, an architecture to interconnect the elements, and software. Many different interconnection methods (e.g., Boolean n-cubes, trees, perfect shuffles) and meshes and nodes (e.g., ones capable of performing floating point, search, and logic operations) have been proposed, as have a number of languages and operating system concepts for exploiting parallelism. The importance of software development cannot be overemphasized. Existing languages, software tools, and performance measurement tools are generally not applicable to specialized architectures.

DARPA has a program in progress to develop and evaluate specialized computers for signal processing, symbolic processing, and multiple functions. The program involves building several prototypes to compare different approaches. Each of the basic areas is discussed briefly below. Candidate architectures include parallel processors, uniprocessor LISP machines, and multi-function hybrids with at least 1000 processors. The project also involves the development of software support, programming languages, and programming environments. NASA should arrange to participate actively in this program through personnel exchanges, joint committees, and review procedures.

Signal Processing

Signal processing involves taking real-time data from a sensor and performing a series of operations on it. These may include transformations (e.g., Fast Fourier Transforms, correlations, and filtering) and are dominated by multiplications and additions. Computational rates in excess of 1 billion operations per second are often needed. Applications include radar, sonar, image, and speech processing.

Modern signal processors use grouped computing elements such as systolic arrays. These involve many simple elements arranged in a highly regular structure which "pump" data from cell to cell in a wave-like motion to perform successive operations. The aim of the DARPA project is to use this architecture to build a system capable of executing 1 billion or more operations per second by 1986 and to proceed toward one capable of 1 trillion operations per second by 1990.

Truly advanced vision systems seem to require about three orders of magnitude more processing capability than is now available. One way to provide this could be through special components interconnected to exploit their inherent parallelism via general-purpose host computers or by high-speed networks.

Symbolic Processing

Symbolic processing deals with relationships between non-numeric objects, and with the inference or deduction of new information through reasoning. Examples of symbolic computation include searching and comparing complex strings and images (e.g., partial pattern matching). Applications requiring large amounts of symbolic processing include vision systems, natural language systems, speech understanding, and planning.

Most processing of this type is now done in LISP; special LISP machines are available commercially, offering computing rates in excess of one million instructions per second. DARPA expects to develop machines with about 50 times this performance level using advanced technology. The Japanese are pursuing a similar program based on the PROLOG language which, though far less widely used at present, is receiving considerable attention.

Multi-Function Machines

A multi-function machine can execute a wider range of tasks than specialized processors but at lower speed in any particular problem area. Its processing elements are usually general-purpose processors communicating either through shared storage or a high-speed network.

A key problem in utilizing multi-function machines is the development of models and algorithms for concurrent programming. Typical models include control-driven, data-driven, and demand-driven representations. In the control-driven case, as exemplified by concurrent PROLOG and parallel LISP, the arrival of the requisite operand set drives actions. This model has the advantage that concurrency can often be specified implicitly. The data-driven model requires the arrival of data at a computing element, whereas in the demand-driven model, a demand for results is necessary to invoke further actions. Of course, composites of these models such as concurrent object-oriented programming have also been proposed.

4.2.4 Networks

Almost every computer in the Space Station will require interprocessor communications. Thus the Station must have a sophisticated networking capability built in during the earliest stages of its development. This network must also

- Possess considerable excess capacity.
- Use standard protocols.
- Have high bandwidth and the ability to accommodate a wide range of data rates.
- Be media-independent.
- Allow widely varying data rates.
- Permit easy expansion.
- Allow the attachment of a large number of devices.
- Provide for fault tolerance and graceful degradation.

Many intrasystem communications methods have appeared in recent years. While they are mostly serial, high bit-rate systems based on coaxial cables or fiber optics, they are generally incompatible because of differences in cabling, protocols, and physical connectors. Standards such as the Institute of Electrical and Electronic Engineers Token Bus Standard (a token-passing algorithm for media access by peer network interfaces) are therefore essential. NASA must stay abreast of new developments in this area and assist in efforts to create additional standards in related areas.

4.2.5 Network Interfaces

The wide variety of boundaries between subsystems demands special attention. For example, the power distribution system should allow mobile devices to acquire power for themselves and for tools and equipment at a wide variety of locations. A robot should be able to proceed under its own power to a failed part, attach a data cable to the network, take measurements from the failed part, and report these to the central diagnostic and control system.

One way to reduce the large amount of cabling required is through the use of intelligent interfaces. These microprocessor-based systems can be installed close to equipment and can perform low-level control, data collection, conversion, error-checking, and communications functions. Such interfaces also reduce the need for centralized computing power.

4.2.6 Computer Languages

Careful standardization of high-level languages is of prime importance to the Space Station's information and control system. The languages should be standard portable ones available on many computers, and the number should be restricted as much as possible. Those selected should also have well-developed sets of software tools and complete programming environments.

Typical candidate languages include Ada and C. Ada has facilities for program and data abstraction, mechanisms for handling timing and concurrency, provisions for control over number representations, and the ability to handle entire software systems as packages. Moreover, DoD's efforts to standardize Ada and enforce its use should ensure the availability of compatible compilers for new generations of computers, and should result in acceptable portability. The C language is a highly efficient, block-structured language widely used in systems programming; it is also the native language of the popular UNIX operating system. NASA should compare languages for a variety of required Station functions before adopting one as its general-purpose programming language.

A specialized language for artificial intelligence will also be necessary to handle symbols, lists, and logical relationships. It should be capable of extensive program recursion. As suggested earlier, the leading candidates in this case are LISP and PROLOG. NASA should also conduct a comparative study of these two languages to determine which is best suited to Space Station applications. Both DoD's efforts to promote the improvement and standardization of LISP, and the Japanese attempt to do the same for PROLOG in their Fifth Generation Computing Project should be monitored carefully.

Robot programming, database querying, simulation, and other applications will require specialized languages, but all statements in these should be translatable into the general-purpose language ultimately selected. Chapter 3 contains more details on the development of programs for robots.

The need to reduce the cost of developing and maintaining software is a primary reason for choosing no more than two modern high-level languages. Ada, in particular, has been designed specifically to promote the development and maintenance of large-scale embedded software systems. Several studies have shown that over half of the total software cost can go into maintenance for large projects. The key to effective software maintenance is to plan for it during the design and development phases. Special emphasis on documentation and the use of software structures that facilitate understanding and modification is required. The Space Station software development environment, as described in Attachment C-9 to the Space Station Phase B request for proposals, deals with these issues extensively.

4.2.7 Real-Time Systems

The Space Station's overall control and information management system will include many real-time systems. Initially these may involve telerobots and CAD/CAM systems as well as traditional control systems. Among the required capabilities are

- Data acquisition at many different rates.
- Coordinated real-time control of distributed devices.
- Millisecond process cycle times.

As more of the Station's operations are automated, real-time computing requirements will increase. For example, robot arm control will require cycle times on the order of 1 millisecond, and joint force or motion control using force or tactile sensors may have to be even faster. This highlights the need for a general purpose language capable of handling real-time and concurrent operations. In fact, the language should be able to accommodate a variety of distributed devices within a single program.

Clearly, development and performance evaluation tools for real-time systems will be required. Real-time software for multiple parallel processes and distributed execution is particularly difficult to develop, and no highly efficient implementation has yet appeared. Since the Space Station software will be one of the first large, complex applications using such features, NASA will have a strong stake in its quality and efficiency. This calls for active efforts to perfect it from the start.

4.2.8 Man-Machine Interfaces

The design of man-machine interfaces will be of utmost importance, as discussed in Appendix 4-C. They should feature touch-menu input, graphics, and voice techniques, and should provide physical cues for robot operations, such as feedback when teleoperating a robot arm. High resolution graphics and novel display techniques will be important, as will methods for interacting with expert systems and other decision support systems.

In particular, interfaces based on voice commands and natural language are desirable to increase productivity. Appendix 4-D describes some of the considerations involved. Such interfaces improve man-machine interaction under a variety of working conditions, including work in a pressure suit. However, they will require the development of a standard natural language shell, restricted continuous speech recognition, and perhaps a limited language translator for foreign astronauts.

Since many Space Station applications will involve critical functions, speech verification will be required to prevent harm arising from inaccurately spoken or interpreted commands. Voice verification will also be needed to prevent interference by unauthorized personnel.

4.2.9 Fault Tolerance

The Space Station's information management system must have the following fault-tolerant features:

- Ability to withstand computer, communications link, network, and peripheral failures, and to re-route channels around a point of failure.
- The highest possible level of survivability for life support systems.
- Fail-operational features for all critical systems.
- Ability to detect erroneous commands and data inputs.
- Recovery to a consistent state after failures.
- Automatic detection of and recovery from failures.
- Allowance for system growth and reconfiguration.

The remoteness, cost, and criticality of Space Station systems require ultra-high reliability of critical core functions as distinct from less stringent payload/experiment requirements. The distributed system as a whole must be able to recover from a failure of any part. This has far-reaching implications for the software that must execute on the system, and is an area requiring considerable additional research and development.

4.2.10 Space Rating of Computer Hardware

One major impediment to NASA's keeping up with the state of the art in computer equipment is the need for space-qualification. Often, by the time equipment has been space-rated, it is already obsolete in the commercial world. This is especially irksome where ultra-reliability is not an issue, as in non-core, experiment-related hardware.

Among the methods NASA should explore to avoid or alleviate this problem are

- Use of non-space-qualified hardware for non-critical functions. Astronauts have already been allowed to take personal computers aboard the space shuttle. This practice should be continued and other standardized computing elements, such as Winchester disk drives, should be tested as missions permit.
- Capsules for isolating standard equipment from the space environment.
- New general standards for space qualification on a series of levels.
- Designs based on military-qualified devices and standards. (A typical example would be the use of microprocessors conforming to Military Standard 1705A. These are highly capable, rugged, and radiation-hardened. The Jet Propulsion Laboratory is currently using them in its MAX multiprocessor system which can be configured to meet a wide range of fault tolerance and speed requirements.)

4.2.11 Technology Advancement Areas

In summary, key technology advancement areas in computer and software systems requiring special NASA efforts include

- Comparative analysis of current general-purpose and artificial intelligence languages.

- Development tools for real-time, parallel, and distributed systems.
- Development of reliable, fault-tolerant, distributed computer systems.
- Methods for protecting non-space-rated computing hardware.
- Metrics and evaluation methods for software reliability.
- Development of specialized VLSI chips for robotics, CAD/CAM, image processing, speech processing, networking, and interfacing functions.

4.3 DATABASE ENGINEERING

Equal in importance to the Space Station's computing and networking capabilities is the definition of the structures and representational characteristics of the databases involved. The Space Station will have a variety of database requirements. It will need, for example, technical information on all aspects of its own design and operation, the satellites to be serviced, and the experiments to be conducted. This data will be necessary both for the automated repair and assembly capabilities that will be developed and to assist human maintenance activities. In general, the Space Station databases must provide

- Incremental growth and reserve capacity.
- High-speed access to large amounts of data.
- Various types of information, including textual, video and experimental data, CAD/CAM representations, programs, and procedures.
- Earth replication backup.
- A standardized structure.
- An intelligent interface and simplified query language that provide easy access for human users, computers, and robots.

4.3.1 Database Contents

The overall database should include

- CAD/CAM data. All contractors should be required to provide this in machine-readable form and in a standard format.
- Activity logs and schedules. These should replace the traditional briefing binders and flight datafile notebooks.
- Repair and servicing data.
- Knowledge collected for use in expert systems.
- Inventory and location data.
- Images of parts for use in computer aided manufacturing.
- Text and pictures for use in simulation, training, and briefing.
- Manufacturing control information and rules for simple fabrication on site.
- Programs for use with robots and other automated equipment.
- Technical information on satellites and experiments.
- Experimental data.

Note, in particular, that information on geometries of components, their locations and interconnections, their assembly or disassembly, tolerances, materials, and surface properties will all be necessary. A significant fraction of the databases will come from industrial systems; hence, compatibility with these systems will be important, and the designers of the database systems must try to achieve this with a minimum amount of translation software.

4.3.2 Data Management Technology

NASA has already initiated a program in data management technology. Its goal is to define an adaptable high-performance system architecture that can serve any conceivable mix of sensors, data processors, mass storage, and communications systems. And, as has been emphasized previously, the Space Station's data management system must be able to survive operationally if any part fails or is damaged. It should also be able to adapt easily to changing applications, preferably without intervention by crew members. Furthermore, it must feature a common data interchange medium between subsystems with widely differing internal technologies.

A truly adaptable data management system requires massive reserve capacity. It should also possess many nodes for accommodating an extensive onboard network. Three technology areas will contribute toward this end: 1) electro-optical components, 2) advanced networks and protocols, and 3) modeling and analysis tools. It is important for NASA to extend its data management technology program to include distributed databases that are fully compatible with distributed processing techniques.

4.3.3 CAD Database Requirements

Computer aided design is one of the most widely discussed automation technologies of our time. It promises to alter dramatically the way products are conceived, designed, pretested, critiqued, and turned into hardware. NASA has shown its awareness of this area's importance by insisting that Space Station contractors present designs in a uniform CAD format. The graphical kernel system is part of a nationwide effort to develop universal representations for three-dimensional moving part arrays that contain physical parameters as well as geometric descriptions.

Uniform CAD standards will allow NASA to evaluate and compare alternative designs with identical test procedures, and to experiment with high-speed processors much more intensively before building initial prototypes. Form and fit, which drive hardware costs up as physical models are revised, can be optimized and tested on a computer screen.

Today, shuttle operators rely heavily on paper backup for every mission. This mass of documents must be condensed, coordinated, and unified into a usable database if the Space Station is to reach its planned level of capability. The database must include all design representations from overall function schematics to CAD images of individual parts, and provision should be made to incorporate new data as it becomes available. Such a database will be required to control robots, operate manufacturing facilities, and assemble structures. As has been stressed previously, allowance must be made for object recognition; that is, the database must include representations of parts and assemblies for use in pattern and visual recognition systems.

For possible future use in automated on-site fabrication and assembly, the database should also include such manufacturing information as process parameters and sequencing details. This kind of stored information will be essential to meet the long-term objectives of creating autonomous intelligent robots and fully operational expert systems. For the IOC, existing orthographic part representations common to most CAD systems should be adequate. However, a mechanism such as bar code identification will be necessary for inventory management and to help teleoperated robots recognize parts.

Chapter 2 notes that these CAD images should be accessible through a Space Station simulator, available to both the crew and ground support personnel. Initially, the system should perform only two functions: 1) storing the support material now kept on paper, and 2) allowing total inventory control. Later, however, it should enable an astronaut to sit at a display and "walk" through the station, seeing depictions of all parts in their current locations, with symbols representing their status. Eventually, this should lead to an intelligent system that continuously works through a variety of scenarios to predict failure modes.

In the mid-term 2000 time frame, the CAD system should be coupled with geometric modeling software to generate three-dimensional graphical representations of parts. These could then be used in heads-up displays, information management systems, and simulations.

4.3.4 Large-Scale Databases

As information needs grow and as expert systems, CAD systems, and intelligent robots come into widespread use in the Space Station, very large amounts of data will accumulate. This will surely be in the terabyte range and may possibly involve many terabytes. NASA must plan now for the secure storage, maintenance, enhancement, and retrieval of this data.

If, as is likely, much of it is stored on the ground, high-speed communications channels will be necessary to move portions to and from space. These links will require high-reliability error-correcting coding. They will also need encryption to provide security for military applications, confidentiality for private company data, and privacy for data such as medical records and personnel information.

As the amount of data increases, onboard databases will require new mass storage architectures with larger capacities, dedicated processors, and special high-speed interfaces. Proper attention to the storage and manipulation of data on an unprecedented scale may be crucial to the entire Space Station effort.

4.3.5 Technology Advancement Areas

In summary, key technology advancement areas for NASA to track or influence in database engineering are

- Distributed databases.
- Methods for managing and accessing very large databases, such as dynamic buffering, associative masking, and self-structuring.
- Intelligent database interfaces accessible by humans, computers, and robots.
- Standards and methods for database security, confidentiality, and privacy.
- Space-rated mass storage systems with terabyte capacities.

4.4 EXPERT SYSTEMS

An *expert system* is a computer program that uses knowledge and reasoning techniques to generate advice and make limited decisions normally requiring the abilities of a highly trained person. Recent advances in computer languages, computer technology, and artificial intelligence have led to widespread interest in and experimental development of such systems. Typical example application areas include electronic circuit design, computer systems configuration, computer aided instruction, medical diagnosis, geological evaluation of sites, oil well dipmeter analysis, locomotive maintenance, and aircraft carrier flight operations.

Such systems have obvious applications in Space Station activities planning, maintenance and repair, system monitoring, environmental monitoring, communications, medical information and diagnosis, and mission and payload control. Factors that particularly favor their use include heavy crew workload, variations in crew training, and the need for Station autonomy.

4.4.1 Development of Expert Systems

The design, debugging, optimization, and validation of an expert system is a major undertaking. One may take years to develop fully, even if design tools are available. Initial versions usually run slowly, yield inaccurate or inconsistent results, and provide misleading explanations of their methodology.

The following steps are necessary to produce a useful system:

1. Collection of knowledge through extensive interaction with human experts. This stage often takes man-years of strenuous effort.
2. Development of a representation for the collected knowledge.
3. Programming of the application system, either in a symbolic programming language such as LISP or PROLOG, or in a higher-level applications language.
4. Validation of the system through consistency checking, testing, evaluation by experts, and operation by potential users.

These tasks are currently done largely *ad hoc*, and are very time consuming. Standard methods must be developed.

A further problem in developing expert systems for the Space Station is the obvious lack of relevant experience. There are no experts with years of Space Station work behind them. Initial experience must be derived from previous missions and simulations, and the systems will have to be refined through feedback from actual operating experience. This places major importance on the development of systems that are flexible and extensible, and on the establishment of procedures and standard methods for deriving knowledge from mission experience.

4.4.2 NASA Knowledge Engineering Laboratory

Because of the difficulty of developing the needed expert systems, it is recommended that NASA establish a knowledge engineering laboratory. This facility could provide a focus for system design, development, coding, debugging, testing, validation, documentation, maintenance, and extension. Its core should consist of packages aimed at solving a few key types of problems such as equipment maintenance, information retrieval, task planning, and monitoring. These packages could include software tools and symbolic simulations. Each simulation could contain a subsystem model and allow fault injection, as well as viewing and analysis of outputs. There should also be tools for consistency checking, verification, and performance evaluation.

The laboratory could serve as a resource for system teams consisting of knowledge engineers, experts on particular subsystems, and astronauts. Team members should be able to access its facilities over a nationwide network such as SPAN or the ARPANET.

The laboratory staff could also assist NASA in the following areas:

- Personnel training.
- Demonstration projects.
- Specification and collection of knowledge.
- Automation of development methods.
- Standards for knowledge databases provided by contractors and equipment suppliers.
- Monitoring of contracts involving the development of expert systems.
- Standards for testing, verifying, validating, and documenting expert systems.
- Development of new tools for automating knowledge acquisition, validating knowledge databases, and comparing alternative techniques.
- Integration of different views of the Space Station (e.g., electrical, mechanical, and life support) in a database system.

4.4.3 Demonstration Projects in Expert Systems

It will be important to test demonstration expert systems in space as early as possible. One approach would be to develop carry-on projects for the shuttle. Another is to develop initial advisory systems for use in both the IOC and ground operations. Early systems may provide no more than: 1) informational responses about operating procedures, security management, fault isolation, maintenance, and repair of basic control systems; 2) simple interactive systems for crew training through computer aided instruction and simulation, crew activity planning, and management of construction projects, experiments, and manufacturing processes; and 3) first-stage robot control.

Early goals should include

- Specification and initial development of a structured database that will eventually contain information about the Station's components, control systems, experiments, and operating principles.
- The codification of mission and payload control procedures and of knowledge gained from previous projects (Skylab, Spacelab, and shuttle missions).
- The development of an interactive onboard workstation capable of running expert systems. It should have a user interface featuring touch menus, voice input, graphical information displays, and functional simulations.
- The demonstration of ground-based expert systems for planning, fault diagnosis and repair, and health maintenance.

The Space Transportation System (STS) offers an environment for aggressive development of expert systems initially as consultants and later as control elements. Consultant demonstrations are under way for shuttle navigation (high-speed re-entry, ascent). Expert systems for control and monitoring of computer resources, structuring of simulations and control of the STS power systems are under development. The structured nature of STS operations lend themselves well to the process of embedding the experience of human flight controllers in expert systems. This will result in the accumulation of extensive human experience rather than its loss through retirements, reassignments, or forgetfulness.

4.4.4 Expert Systems in the 2010 Time Frame

In the 2010 time frame, onboard expert systems should function as part of an integrated information and control network, capable of long-term automatic operation including self-repair. The network should feature massively parallel processing, qualitative decision making on the basis of incomplete or even partially inaccurate information, and accumulation of expertise on how to solve a wide variety of operating problems.

Real-time response should be possible for information and simulation systems, especially in crisis situations. All network and machine operations should be transparent to the user. Interfaces should be voice or touch-menu driven. Each early subsystem should allow the introduction of more competent and powerful hardware and software as it becomes available. Note that all of this assumes both reserve capacity and modularity in the network and in its computing elements.

Later systems should also feature

- Self-learning and modifiability.
- Onboard updating of the knowledge database, extension and reprogramming of the system, and revalidation of its consistency, accuracy, and fault tolerance.
- Effective handling of uncertainty and missing information.
- Automatic collection of knowledge for inclusion in later versions.

4.4.5 Key Technology Advancement Areas

The areas in expert systems requiring development emphasis are

- Software tools and standards for consistency checking, verification, validation, and performance evaluation.
- Space-rated workstations.
- Implementations on special-purpose and advanced architecture computers.
- Real-time operation.
- Integration of systems under central control.
- Reliability and fault tolerance.
- Implementation of common-sense reasoning.
- Combinations including quantitative models and real-time constraints.

4.5 MATHEMATICAL METHODS

Whereas this report has emphasized applications-oriented research in information management, it should be remembered that the useful techniques of today had their origins in what were once obscure mathematical disciplines.

Progress in technical areas such as computer networks, fault tolerance, real-time systems, software reliability, CAD/CAM, distributed databases, and expert systems, depends strongly on the development of adequate mathematical foundations. Subjects such as sensitivity analysis, optimization, graph theory, nonlinear analysis, computational complexity, finite mathematics, linear and dynamic programming, and information theory require further exploration. Appendix 4-E describes several relevant mathematical topics in more detail.

It is recommended, therefore, that NASA pursue a development program in mathematics with an emphasis on crucial areas related to computer systems, computer algorithms, artificial intelligence, and special methods such as function-level programming.

Chapter 5

INTERACTIONS WITH PRIVATE AND GOVERNMENT SECTORS

5.0 SUMMARY

Interactions with other public and private institutions will be a key element in developing the Space Station and using it effectively. NASA should implement new incentives to encourage significant contributions from industry, national laboratories, and academia, and it should also take full advantage of major external advances in technical areas such as automatic control, computer aided design and computer aided manufacturing (CAD/CAM), and robotics.

The Space Station can be of significant use to other institutions as an experimental laboratory, for demonstrations of space manufacturing and assembly, and as a base for satellite servicing and other space operations. Space Station technology in automation and robotics can also result in general advances in factory automation, in the development of hybrid teleoperator/robots (telerobots), and in the standardization of computer languages, networks, and databases. Telerobots, in particular, should have widespread applications in handling toxic materials, construction, machine repair and maintenance, commercial and service work, military operations, agriculture, and services for the aged and disabled. Space Station applications can also demonstrate automated inspection systems, materials handling by remote control, and advanced manufacturing systems.

5.1 OVERALL STATEMENT

The Space Station program, including its automation aspects, will be justified by its benefits to society. Conversely, many public and private institutions will help make a highly automated Space Station technically and economically feasible. *Economic incentives should be designed to elicit contributions from these institutions.*

Besides NASA, the institutions involved will certainly include other U.S. government agencies, universities, industrial firms, and foreign governments. We shall discuss interactions with each of these. However, we will categorize key interactions as follows:

First, NASA will, in addition to its own internal expenditures, pay others to develop automated systems and techniques for the Space Station.

Second, industry, government, and universities will use the Space Station's unique facilities in two ways: those subsidized at least in part by NASA (e.g., for training or basic science) and those paid for by users. Fees for the latter will partly offset the costs of the Space Station.

Third, and perhaps most important, are the external effects. That is, the construction and evolution of automated systems for the Space Station will produce new technologies and procedures that will benefit society in many ways. These benefits could include the standardization of computer languages, development of robots and expert systems with terrestrial applications, and medical research in space undertaken jointly by the U.S. and foreign governments.

5.2 INSTITUTIONAL CONTRIBUTIONS TO THE DEVELOPMENT OF SPACE STATION A&R

We shall first discuss incentives for institutions to contribute R&D efforts to Space Station automation. Here we confine ourselves mostly to principles rather than contractual details. Second, we discuss specific kinds of technology transfer from the private sector to the Space Station.

5.2.1 Incentives

To design incentive mechanisms, we need to discuss the objectives of both NASA and its contractors when they contract for development work in robotics, automation, and artificial intelligence (AI).

What does NASA want?

NASA's primary objective is progress in automation and robotics for use in the Space Station. Specifically, NASA could use two approaches:

- It could sponsor more fundamental, less goal-oriented work. Such work is open-ended, and its course and destination cannot be pre-specified. The scientist follows where the problem leads with the aim of increasing understanding. Such work can sometimes result in a giant step forward. The difficulty is to couple it to mission objectives. In an industrial laboratory, this coupling can sometimes be accomplished by the sensitive intermediation of skilled R&D managers. It is not clear to what extent such coupling can be accomplished in *contract* research, even in the presence of a technically outstanding overview committee.
- NASA could lead the R&D by setting out a sequence of short-term, small-scale technological problems, a little beyond the state of the art. NASA would define this sequence using its own internal technical expertise. Providing incentives for such work is a standard problem; presumably the solution would involve periodic assessment and renewal of contracts contingent on accomplishment. This kind of project would appeal more to engineers than to those involved in pure research.

What do the contractors want?

The objectives of contractors are far from uniform. We will consider separately industry, government and national laboratories, and academia.

Private Industry

Private industry wants to maximize long-term profits from production, cost-reduction, product innovation, and expanded markets. Most industrial laboratories are not interested in working, or will not do high-quality work, for cost plus a percentage. From the point-of-view of a profit-maximizing firm, R&D is a high-risk activity whose output is difficult to appreciate; hence, some additional incentive is required.

These considerations lead us to suggest that

1. *Incentive contracts* might provide for payment dependent on the success of the project, and exclusive rights to the new technology including, for example, sale of the resulting product to NASA, probably at a discount.
2. NASA might offer to private industry those projects that give promise, if successful, of *future production contracts*. NASA would have to be prepared to explain to the public that such contracts are not a subsidy to the industrial firm, but rather a normal reward for a risky undertaking.

National Laboratories

The objectives of government, national, and other non-profit laboratories include assurance of continued existence, growth, and maintenance of long-term scientific interests and styles. Here cost-plus contracts are a familiar and acceptable mechanism.

Academia

The objectives of academic organizations are similar to those of national laboratories, but with some differences. Contracts may be made with institutes and laboratories within the university, but here the individual researchers (professors) have much more influence on policy and research. Their objectives include recognition by their academic peer groups. It follows, for example, that open publication of research results is essential. Their research interests and criteria for success do not necessarily bear a relationship to NASA's objectives. Therefore, it is an important problem for NASA's management to identify individuals and groups at universities who are both creative and will try to help meet NASA's objectives. One means to this end is to maintain a strong R&D capability within NASA.

Note that even for national laboratories and academia, cost-plus contracts, while acceptable to the contractors, may not be desirable from NASA's point of view, since they lack incentives for efficiency.

We mention finally two additional incentives for an industrial firm participating in Space Station development. First, by being intimately involved in the project from the start, it may secure a long-term pipeline to important technical developments. Second, perhaps not trivially, the project will have a bonus of prestige both inside the industry and in society as a whole

It may be necessary to mount special efforts to encourage groups that would not normally be NASA contractors to participate in the Space Station effort. The use of contests, award programs, and other related techniques may be particularly applicable here.

5.2.2 Private-Sector Developments Applicable to the Space Station

There are areas of technology where the private sector has a clear lead, and where NASA could well benefit by *leveraging* development or by directly *exploiting* commercial products and techniques. As discussed in Chapters 2, 3, and 4, this may require some effort to develop new methods for space-qualifying terrestrial hardware. As will be noted in Chapter 6, the Space Station can be designed with the objective of increasing the use of systems developed for Earth markets. Fields chosen as examples are

- Automatic control systems.
- Environmental control and agriculture.
- Industrial and undersea robotics.
- Fluid handling.
- CAD/CAM technology.
- Materials transport in space.
- AI systems.
- Navigation systems.

Automatic Control Systems

Private industries, universities, government laboratories, and private institutions are vigorously developing fault-tolerant control procedures for defense, manufacturing, and process applications. Most researchers agree that a hierarchical (deterministic) approach is the most appropriate for the wide range of practical needs. Major program efforts are currently concentrated in the following areas:

- Use of state-of-the-art microprocessors such as the 68000 and 8086/8087.
- Standardized programming languages.
- Fault tolerant architecture.
- Local area network protocols.

The scale of these efforts makes it appear wise for NASA to adopt a standardized chip set, language, communications protocol, and architecture from the private sector.

Environmental Control and Agriculture

Recent significant developments in aircraft, dwelling, and factory environmental control may be applicable to the Space Station. In the long term, progress in hydroponics, aeroculture (nutrient-rich mists), and large-scale microculture may result in technologies useful for food production and environmental control in space.

Industrial and Undersea Robotic Arms

Robotic or teleoperational arms are in widespread use today in factories, in oil rig activities, and undersea. These technologies might be adapted to space by taking into consideration issues such as lubrication and low-mass structure. Since the cost of space boost can decline sharply, NASA may need to re-examine the cost tradeoffs of developing a completely separate manipulator technology.

Fluid Handling

High-speed, two-way, fluid flow transfer systems have been developed for terrestrial applications such as refueling race cars, combat vehicles, and aircraft. Fluid handling requirements in space are complicated by low gravity and the use of cryogens or hypergolics, but there may still be ways to use Earth-developed components. Particular attention should be paid to two-way flow, quick connect/disconnect couplers, and self sealing lines, because of the high value of fluid in space. Operations in milli-gravity environments, such as at the ends of tethers, may allow use of more conventional fluid handling methods.

CAD/CAM Technology

Manufacturing requirements have led industry to develop excellent three-dimensional representations of parts via CAD. As discussed in detail in Chapter 2, this technology could aid astronauts in operational planning activities and in simulating functions such as docking or extra-vehicular activity (EVA). Databases used initially to hold onboard parts inventories could evolve into full-scale station representations. Using CAD databases for robotics planning and expert systems is discussed in Chapters 3 and 4.

Compatible CAD representations, provided by all contractors, can allow the Space Station to be managed without the large amount of paper currently required for the Space Transportation System. This will save both overhead and information access time. Scenarios can be tested quickly with sophisticated software.

NASA has many reasons to be interested in CAD and CAM. Space hardware is expensive partly because of the modeling, tests, and inspections each part must go through before a design is optimized. CAD/CAM should enable contractors and NASA to actually go through more iterations in less time, using less manpower.

The fact that space hardware has very small production runs usually means high cost. Because there are few economies of scale, it does not pay to automate production. But CAD/CAM methods may make it possible to produce specialty parts in small lots with sophisticated turnkey systems, taking a part from computerized representation to physical form in a short time. This is of special interest to NASA.

Materials Transport in Space

Recently, software and, to a more limited degree, hardware for materials handling, has evolved significantly. These new developments should be considered for use in the Space Station for handling and moving of solid objects and materials. It may be better to use the best industrial robotic practice rather than inventing new designs for space.

Artificial Intelligence Systems

NASA can use AI developments to create larger, deeper knowledge bases. Knowledge-based system design tools will speed the programming of expert systems, reduce development time, and cut costs while improving code quality.

Navigation Systems

Automated navigation systems for teleoperated spacecraft, platforms, and satellites can be developed from technology now existing in the private sector. Using radio signals from the Department of Defense (DoD) NAVSTAR/Global Positioning System

(GPS) satellites, such systems could provide accurate positioning, velocity, attitude, and docking information in a straightforward, compact fashion. Complete GPS receiver and antenna assemblies that do not require knowledge of the classified code are now available in packages the size of a book. Centimeter positioning and milliradian attitude accuracies are achievable on Earth.

These examples all have the common feature that enormous industrial and university efforts have already gone into technology development. NASA should evaluate the economic and scheduling benefits of adopting or adapting this work versus a new development. It should also examine how the Space Station can be designed to make economic use of these terrestrial systems.

5.3 USE OF THE SPACE STATION BY OTHER INSTITUTIONS

We now discuss, in turn, use of the operational Space Station by industry, other government agencies, universities, and foreign governments. Such use could involve a variety of economic arrangements. For example, an industrial firm might rent a "room" in the Space Station, or a unique piece of equipment, for special experimental or manufacturing purposes. At another extreme, NASA might sponsor experimental work in space by a university researcher.

5.3.1 Use of the Space Station by Industry

The Space Station will offer a variety of unique industrial opportunities for research, development, manufacturing, and services. These include

- Access to sustained accelerations between zero and high accelerations.
- High vacuum.
- Isolation from disturbance and contamination.
- An abundance of cosmic-ray primaries.
- Observability of the earth.
- Assembly, maintenance, and repair of satellites.
- Assembly of large-scale, low-gravity structures such as factories and energy plants.
- A staging base for lunar exploitation.

Drawbacks of space, from the potential user's point of view, include

- Lift costs.
- Insurance costs.
- Space qualification and "man-rating" of hardware.
- Need to fit into constrained volumes.
- Power and heat rejection limitations.
- Lack of reservoirs of raw materials.

Many of these constraints will fade as lift costs fall and as material accumulates in orbit.

From an economic point of view, designing for growth means designing for low incremental cost of new uses of the Space Station. Many proposals discussed elsewhere in this report can help achieve this end, e.g.,

- Modularity and micro-modularity.
- Accumulation of resources in orbit.
- An optimal level of automation (this level rises as automation and robots become less costly compared to human labor).
- A Space Station designed for reasonable maximum (increasing) use of terrestrial technologies.

Space Station costs can be partially recovered through rental of its facilities to industry. The problem is to establish rental fees that would attract usage and eventually cover costs. Space Station costs range in a complex hierarchy from fixed to variable. Highest in the hierarchy are facilities costs required to bring the evolving Space Station to a general configuration at a given time and to operate it. These costs will likely increase with time. Depending on policy, federal tax revenues might cover general facility costs. Lower in the hierarchy are specific facility costs permitting particular classes of industrial use. These might be borne in part by the particular industrial users. Lowest in the hierarchy are variable costs which depend on the quantity of a particular use (work hours, number of occurrences, power usage, etc.). Direct fees should cover these variable costs.

5.3.2 Use of the Space Station by Other Government Agencies

Use of the Space Station by government agencies other than NASA should be encouraged. Personnel exchanges between NASA and these organizations should occur during all stages of the Space Station program.

During the design stage, NASA should endeavor to create a station that will be of maximum use to other government agencies, as well as to commercial and international interests. In many cases, NASA may have to make educated guesses about what services other organizations may require. Agencies that do not typically use space assets will not know what to ask for in Space Station design. On the other hand, any that do admit to needing a special design feature stand in jeopardy of being charged part of the development costs *now*, in return for transient benefit *later*.

Other technologically advanced government organizations could help NASA in the design of the Space Station. The Defense Advanced Research Projects Agency (DARPA) of the DoD has competence in AI and robotics, as do various military laboratories. The Bureau of Standards of the Department of Commerce has AI and robotics capability oriented toward flexible manufacturing. NASA should draw on the expertise in these agencies to help evaluate proposals in AI and robotics.

NASA personnel should be sent to work in the other agencies' laboratories for on-the-job training and to cement working relationships. One- to two-year tours would allow a NASA person to obtain enough expertise to effectively direct the contractors' AI and robotics efforts. In exchange for the personnel on loan from NASA, the host agency should supply its experts on a part-time basis during the definition phase of the Space Station to guide and monitor contractors' efforts.

Several agencies could use an operational Space Station (taken to consist of both manned and unmanned elements). The National Oceanic and Atmospheric Administration (NOAA) has responsibility for weather monitoring from space. Even if the gathering of weather data is transferred to commercial interests, someone will have to do R&D on advanced payloads. And even if NASA does the actual R&D, NOAA must define requirements. Similarly, the Departments of Interior and Agriculture and the Environmental Protection Agency could gather valuable data from space to aid in their work. The Department of Commerce should have an interest in unique manufacturing processes or services practical only in the space environment.

NASA traditionally cooperates with the Department of State on international programs. There may well be considerable international involvement in the design and operation of the Space Station.

Military uses of Space Station capabilities (either for R&D on future military systems or for actual operations) are being debated. Policies should be developed to maximize the efficacy of the major United States investments in Space Station capabilities.

5.3.3 Use of the Space Station by Universities and Research Institutions

Many of the conditions and facilities that make the Space Station attractive to industry will also make it attractive to academic research. In addition, it will provide unique opportunities in astronomy and other non-industrial fields. The Station's utility was noted by Professor Peter M. Banks in his statement[*] before the House Subcommittee on Space Science and Applications as follows:

> *Preparation and advocacy for scientific use of the Space Station has been underway in the science and applications communities since the early 1970s. Workshops and other meetings have been held among scientific disciplines to examine the utility of coordinated facilities having a scale and complexity not accommodated on automated spacecraft. Studies conducted in many disciplines, including the life sciences, materials research, solar-terrestrial research, and earth observations have considered the opportunities offered by a large resource Space Station and have concluded that important tasks could be effectively accomplished with this facility or facilities coordinated with it.*

Scientific payloads may have special requirements such as ultraclean environments. In addition to basic research topics in the sciences, particular topics of fundamental engineering research might include space telecommunications, large space structures, advanced materials research, advanced electronic design for the space environment, and applications of automation and expert systems. In fact, such science and engineering research, while undertaken by universities, could be expected to have long-term benefits for NASA's mission and for the Space Station in particular.[†]

5.3.4 Use of the Space Station by Foreign Governments

Opportunities should be sought for foreign participation in Space Station activities, where there is both technical complementarity and an opportunity to increase international amity and reduce tensions.

Working arrangements with the space programs of United States allies such as Western Europe's European Space Agency and Japan should be explored in terms of both finance and technology. NASA cooperates extensively with foreign countries (e.g., Apollo-Soyuz, Spacelab, and scientific programs). From a political point of view, much can be gained in international prestige and visibility by encouraging foreign support for the Space Station. From a technical point of view, NASA should examine the research capabilities of prospective partners. Once this is done, NASA should then attempt to integrate these partners into the Space Station program to make the best use of their technical expertise. NASA should develop a mechanism for shared funding with foreign governments in research and development areas of mutual concern. Perhaps a consortium whose participants share costs and results would be appropriate.

We should also watch for areas of collaboration with Soviet scientists, both because of potential technical advantages, and in the hope of achieving some modest reduction in international tensions.

5.3.5 Cost Sharing of Terrestrial-Based Facilities

Extensive use of Earth-based facilities is anticipated during the Space Station's lifetime. This section discusses the sharing of launch support, communications, and experimental facilities.

Launch Support Facilities

The unique needs of the space shuttle will dictate concentration of launch and support facilities. Some sharing of additional facilities should be considered with DoD, other friendly governments, the USSR, and China, as part of a development plan for international cooperation.

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[*] P.M. Banks, Statement before the Subcommittee on Space Science and Applications, Discussion on NASA's Task Force on Scientific Uses of the Space Station, Thursday, February 9, 1984.

[†] A more detailed discussion of these issues will be available in a forthcoming report of the Task Force on Scientific Uses of the Space Station, Space and Earth Science Advisory Committee (SESAC), NASA.

Communications

The Tracking and Data Relay Satellite channel capacity required by a large, active Space Station may well grow geometrically as new uses evolve. There is an opportunity to share communications facilities, channels, and Earth stations in commercial use.

Experimental Facilities

Scientific research in the Space Station will require extensive Earth-based support. Here again, the use of existing facilities, shared databases, instruments, procedures, and the like will increase effectiveness and lower overall costs.

5.4 EXTERNAL USES OF SPACE STATION TECHNOLOGY

Below, we mention several varied areas of automation and robotics for which the Space Station can serve as a focus of significant progress, and describe potential applications of such progress and their benefits, both public and private. These areas include telerobots applicable to terrestrial use, and the standardization of computer languages, networks, and databases. These examples are meant to illustrate, but not exhaust, the possibilities.

5.4.1 Telerobots

Telerobots developed for the Space Station show promise of terrestrial application in many areas.

If a completely automated manufacturing system is developed for space, such as for the production of gallium arsenide single crystals and the subsequent processing into semiconductor devices, the following benefits could result:

- Advanced robots with integrated visual, tactile, and other sensors.
- Improved performance of robots due to careful design and better materials.
- More dexterous end effectors.
- Expert systems for diagnosis, repair, control, and planning of many functions.
- Advanced programming methods for robots using CAD/CAM databases.

Automation technology developed for space will have a significant impact not only on manufacturing industries but also on the service industries that employ 80 percent of the U.S. workforce. For agriculture, construction, work in the deep seas and deep mines, human services (particularly those directed to the disabled and the aged), the military, safety and security, and health, a major contribution of new space technology will be in the development of telerobots.

Such devices, in the Panel's opinion, may become the most common robots, far exceeding factory robots in number. They could be our future electromechanical servants, machines combining advanced high technology engineering with interactive human control. Human intelligence with its enormous versatility will analyze new tasks, select the sequence of operations (often through stored programs), and solve problems, thus providing the higher levels of intelligence that current machines woefully lack. Descriptions of a few potential application areas for these systems will illustrate their generality.

Toxic and Radioactive Materials and Hostile Environments

Robots can perform manipulation and inspection at sites that are dangerously radioactive (near or inside nuclear reactors) or that contain toxic gases, biochemicals, or other pollutants. Specialized tools can be developed for repair or maintenance of "hot" equipment, and for transporting or removing toxic materials. The latter tasks should be made repetitive so that a telerobot can perform them unattended.

There are many hostile environments on Earth where telerobots could be used. The nuclear industry could use them to enter radioactive areas for examination, inspect welds, and manipulate stuck valves. Such devices would be programmed to know their own "reactor environment" and could even grasp and remove injured people from the scene.

Applications in the Construction Industries

Applications in construction include loading, unloading, and moving heavy materials, laying bricks and cement blocks, automatic trenching and other earth-moving operations, and arc welding. These systems may be particularly useful in large construction projects such as dams and bridges, as well as for maintenance such as sand-blasting and outdoor spray-painting.

Repair and Maintenance of Machines

Another use is for repair and maintenance of machines, especially in hazardous conditions. After the teleoperator guides the robot into position and chooses the appropriate stored program, the robot could remove and replace defective parts, lubricate, test, clean, and perform other routine operations. As an automobile mechanic's helper, it could remove and replace wheels, steam-clean the engine, and unbolt and bolt accessories. Ultimately, as research leads to the development of expert systems for diagnosis and repair, robots could assist the mechanic by invoking stored programs, each specialized for the particular model of automobile under repair and for the job at hand.

In space, the deep seas, deep mines, the polar regions, and other inhospitable or dangerous regions, economic repair and maintenance by robots will be a driving force in expanding extraction, production, and even manufacturing of useful products. It will permit automated processes to be conducted with supervisory personnel not physically located at the dangerous sites.

Applications in Private and Public Services

There are many mundane commercial and service tasks that machines can do. Potential applications include washing windows of tall buildings, cleaning and painting exteriors, repairing street pavement, separating waste, disposing of toxic waste, cleaning institutions, firefighting, acting as mobile aids for police in handling dangerous materials and people, or doing automotive lubrication, refueling, and tire changes. These applications will have to await the development of specialized machines with large enough markets to warrant affordable mass production.

Military Applications

Programs to introduce robots into military operations are now of some interest. Many military personnel are engaged in ordinary service tasks such as loading and unloading munitions, construction, maintenance, and refueling tanks and vehicles. Telerobots could also perform dangerous tasks under battle conditions, such as mine detection and disposal, reconnaissance, perimeter surveillance, and other operations. Although these machines may be expensive because of the rigid requirements for field-worthiness, their market is potentially large because their use reduces casualties and increases efficiency in performing hazardous operations. A substantial increase in the efficiency of service and "on-line" military personnel is possible (NRC 1983). A decrease in the number of personnel can be projected.

Agricultural Applications

Many areas of agriculture could benefit from the use of more intelligent autonomous robots. A mobile robot with specialized end effectors (hands and tools) would be valuable for stoop-labor applications, such as pruning, picking, and cultivation. The range of materials handling tasks in horticulture, aquaculture, and hydroponics can be extended. Interesting research is being conducted in Australia in automated sheep shearing. In the long term, agriculture and ecological management will profit from techniques developed for large-scale life support in space. Advances in modeling methods, biological recycling techniques, and robotics could have major effects on Earth.

Applications for the Aged, Infirm, and Disabled

The development of mass produced low-cost robots would be particularly important for the millions who are physically disabled (i.e., those who are blind, bedridden, or confined to wheelchairs). These machines would free them from the need for continual human care and allow them to become more involved in ordinary activities.

Servicing and Manufacturing

Space Station subsystems will have to be inspected, repaired, or replaced in a semi-autonomous manner. For example, an experiment might need to have its film canister exchanged bi-weekly, or a mechanical joint might have to be lubricated. The systems integration and machine perception developed for such applications will have many uses on Earth. Semi-autonomous robotic servicing systems would be most appropriate in large, complex but well structured systems such as ships or factories, but could also be economically justifiable in high-volume applications such as aircraft or automobile fleet maintenance.

Another requirement in space will be the location and repair of structural damage caused by micrometeorites and other debris. Automated flaw detection in composites, coatings, and other advanced materials will be a natural fallout of such space station capabilities. Technology in this area is badly needed, for example, in the aircraft industry, for products such as wing sections and structural skin elements. Considerable progress will result from NASA and corporate cooperation in developing the next generation of production aids.

As discussed in Chapter 3, the Space Station's advanced telerobots will demand improved sensors and sensory processing. Better tactile sensors, faster vision processing, short- and long-range scanning, laser ranging, and a variety of non-destructive evaluation probes will all be necessary. Such developments will also be welcomed for terrestrial applications ranging from telepresence to third-generation robotic systems. Manufacturing systems will require much less structure as a result of new sensors and high-speed, integrated sensory processing.

Space Station automation developments will also advance the state of the art in manufacturing design. Advanced CAD/CAM system modeling and planning are progressing quickly in industry but, as discussed earlier, NASA requirements will help raise these areas to new levels.

The Space Station's use and continued development of a CAD/CAM system to model, coordinate, plan, and design operations will be of great benefit to Earthbound systems. One complex problem is modeling and coordinating the actions of several arms. New generalized methods for solving problems of this type would have direct applications to similar terrestrial manufacturing.

Construction

Space construction represents an excellent way to prove the worth of a telerobot in reducing EVA time. Once a truss system is decided on, a device to build it can be designed. If some uniformity can be established, the space mobile constructor could lead to similar terrestrial devices. Mobile construction telerobots of this type could be used to build modular homes, geodesic domes, and buildings or bridges. If carefully designed, these structures might also later accommodate robots for inspection, cleaning, or repair.

5.4.2 Standardization of Computer Languages, Networks, and Databases

NASA's adoption of standard computer languages, networks, and databases will promote their subsequent adoption by the private sector.

Earlier sections discussed the importance of designing the Space Station for growth and cost-effectiveness in the year 2010. This task is particularly difficult concerning computers because of rapid technological advances. Few fields change with such frequency and magnitude. By the year 2010 we can expect at least two to four entirely new generations of computers with vastly enhanced capabilities. Indeed, their use will increase the capacity for new and more extensive experiments and automation in the Space Station. The Initial Operational Capability Space Station must be able to incorporate the capabilities of these new computers as they become available.

This problem will be ameliorated somewhat by the fact that not all aspects of computer technology change as fast as the hardware. Interconnection mechanisms, computer languages, and database systems evolve much more slowly. Some languages have been with us now for 25 years or more, and important new languages will probably have similar lifetimes. Communications systems, languages, and databases have thus become the basis for portability between generations of computer hardware. Similarly, they can be the basis for accommodating change and growth of computer technology for the Space Station. New generations of computer hardware are usually designed to accommodate existing standard communications systems. With a modest software effort, a database system used on one generation of computer hardware can be used on the next. Thus, programs written in a high level language that run on a computer of one generation can be expected to run on one of the next generation as well. It is important, therefore, to use standard communications systems, databases, and languages. As new generations of hardware arrive, the vendors will produce the compilers, communications software, and database systems to function with common standards.

The standardization of languages, communications, and databases has many benefits besides accommodating generational changes in computers. First and foremost is the ability to easily incorporate software and data developed elsewhere if the standards are ones commonly used in industry and government. This opens the doors to a vast market of useful products. While some of the Space Station's needs will be unique, others will be shared by industry or other segments of the government. Second, standardizing on widely used languages and databases will allow NASA to obtain staff from a sizable pool of trained people. Third, the cost of developing and maintaining software and databases will be lower. We should note that standardization need not result in technological backwardness if careful choices are made.

5.5 REFERENCE

NRC (1983) *Applications of Robotics and Artificial Intelligence to reduce risk and improve effectiveness: A study for the United States Army*, 91 pp, Committee on Army Robotics and Artificial Intelligence, Manufacturing Studies Board, Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington, D.C.

Chapter 6

BROADER OPPORTUNITIES

**The Space Station is a means to
broader opportunities
in time, space, and society.**

6.0 SUMMARY

Prior to the Space Transportation System (STS), space programs focused on achieving well-defined goals in specific time frames. The STS was designed to support multiple projects over many years. This trend will go on. No single project will ever fully define the Space Station. It will change over time, spread over space, and it will mean different things to different people. Despite our best predictions, the Space Station in the year 2010 will probably not resemble what anyone today would expect. And yet, current design decisions must prepare for and accommodate both short- and long-term goals.

We should not consider the Space Station as a frozen image, but rather, as part of a three-dimensional *continuum* that includes

- *Time*: The Space Station represents a continuing human presence in space. It will support new and changing missions, stimulating growth as years pass. Section 6.1 discusses this.
- *Space*: The Initial Operational Capability (IOC) Space Station will contain the seed elements of a growing space presence, expanding in and beyond near-Earth space. Some components will create opportunities well beyond Earth orbit. Section 6.2 covers this aspect.
- *Society*: Benefits of the Space Station need not be restricted to space or to the period of initial development and implementation. The program can extend society's reach by expanding its access to space. It will support machines that use solar energy, and nonterrestrial materials that seed growing industries. New wealth can be created for Earth. Advanced space systems will support increasing populations beyond Earth's confines.

America is planning a project that will last more than a human generation. Its future space systems must remain flexible to absorb *expected* technological improvements, thereby accommodating growth. Section 6.4 explores some *breakthroughs* to prepare for, and section 6.5 lists recommendations that can create and help us prepare for broader opportunities.

6.1 A CONTINUUM IN *TIME*

Previous chapters have discussed the evolution in time of a planned Space Station. Chapter 2 describes the Space Station from the point of view of the year 2010, listing design tenets, and warning of pitfalls. Chapters 3 and 4 examine how the expanding technologies of robotics and information management will affect Space Station design and operation. Chapter 5 touches on how developing practices in manufacturing will affect the construction and maintenance of the Space Station.

While these are far reaching discussions, a few points must still be made about an *evolving*, growing space capability.

Prior space ventures were limited in time, design, and the community of people involved. To some extent, this reflected the constraints of a less mature technology base. For example, Skylab demonstrated that humans could live in Earth orbit for extended periods, given resupply from Earth and intensive support by teams of mission controllers. Like the Gemini and Apollo systems, the spacecraft was optimized around a fixed architecture and not designed to grow or change. Much the same is true of the Soviet Soyuz/Salyut space station system. The United States' STS is more flexible. It has demonstrated a wide range of short-duration manned capabilities. However, in its present form, it still requires expensive support by mission controllers and Earth-based centers. Unfortunately, it is still considered to be a design frozen in time.

The new challenge is to make systems that actively support expanding human endeavors in space, but require minimal human attention. Advanced A&R should handle routine tasks, freeing people in space to do higher-level work. The Space Station is only part of this development. All people involved in design should view the IOC Station as one part of a continuum of activities involving rapid growth of terrestrial technologies into space. It is a means to growth, not an end in itself.

Designers face a common quandary: how to give a system a long lifetime while allowing for growth and change. For example, B-52 bombers have evolved over 30 years. Because of their large size they could accept many additions and modifications. This was important in the 1960s and 1970s, when the design cycles of large aerospace craft often lasted over a decade. But these cycles are shortening as computerized methods of design, testing and construction improve. Commodious space systems could accept many new automation techniques allowing both short upgrade schedules and long overall lifetimes.

Because a well planned Space Station can evolve and grow larger, the Space Station program can build gateways to broader opportunities. As the program matures it will create and be led by new industries, building a progressively more efficient and supportive infrastructure on Earth and beyond.

The "Space Station Era" may well resemble a stage in the expansion of the U.S. transportation system. In 19th century America, for example, both railroads and the factory systems that made locomotives and rails expanded interdependently. Space systems offer opportunities for similar developments, both off and on Earth.

Space systems can be segmented in function and location. The infrastructure need not be *physically* integrated, as in most aircraft or the space shuttle; individual modules are much easier to upgrade. Evolving space systems industries can respond to future needs, just as railroads were able to meet the transportation requirements of a growing country better than could canal-based networks.

The STS and its advanced versions can influence Space Station growth. Applying A&R to the STS can improve its efficiency and decrease operational costs. A&R can, for example, reduce the number of support personnel, improve crew effectiveness, and provide greater access to payload operations.

Many nations and groups will construct and operate orbital facilities in the 21st century. Some world leaders and ordinary citizens celebrating the inauguration of the Space Station will be able to remember flights of the first commercial airplanes. At the rate technology is evolving, we can expect changes of far greater magnitude to follow the original Space Station. New terrestrial industries must anticipate and design for these changes.

6.2 A CONTINUUM IN *SPACE*

As the Space Station evolves, it will be associated with a growing number of systems dispersed widely through space. Initially, the systems will be launched from Earth to be used as is or assembled into larger units. The early Space Station could begin to repair itself and build facilities from such items as the many external tanks, each of which is now thrown back to Earth following STS launch. In-space assembly and manufacturing can lead directly to facilities on the moon which can grow, primarily using lunar materials. The stage will then be set for expansion beyond cis-lunar space.

Modern industry is linked over wide regions by transport, power and communications. These interconnections allow regional groups to accomplish much more than can a single factory or individual. Widely dispersed space systems will also be connected.

Eventually, great resources of power, materials, and control of physical processes will be available to them over large regions of space. The Space Station is the starting point.

6.2.1 Dispersal in Orbit

Already, an independent, polar-orbiting, man-tended platform is considered an important part of the IOC Space Station. This trend toward distributed infrastructure will grow as transfer vehicles move to and from higher orbits. Separated hardware will feature standardized systems, shared operating procedures, and coordinated goals.

Dispersal in orbit will allow experiments or industrial processes that would be incompatible in the same structure. For instance, sensitive optics should be kept away from the inevitable outgassing of habitation modules and emergency releases of reactive compounds used in materials processing. Habitats, in turn, should be separated from space industrial units dealing with high-energy conversion of metals, impact experiments, or transfer of liquid propellants. These diverse elements could be co-orbiting or connected by long tethers.

Multiple elements dispersed in various orbits could support experiments requiring high gas-pumping rates, protection against thermal changes, shielding from electromagnetic signals, low-level but long-term acceleration (using tethers, spin, or electromotive forces), or isolation.

Many programs may be performed reliably only in space. Possible examples are studies of the growth of large numbers of plants or animals in a completely sealed environment to study trace-element metabolism or very low-level toxicology. It is virtually impossible to seal a large volume on Earth (say one the size of the ET, which is approximately 9 meters in diameter and 50 meters long) against trace-level leakage of gases or dust from outside. In space, however, ETs might be used as large "test tubes" at reasonable unit expense. Simple telerobots could help conduct experiments or demonstrate advanced support systems over long periods.

A key function of the IOC Space Station might be to rework used satellites or bulk materials from Earth into new components. For example, external tanks (ETs) might be outfitted as experimental chambers, or the twenty-five ton lots of ET aluminum might be formed into new shapes. Excess propellants, dense bulk materials in volume-limited flights, or even waste from life-support modules, may be accumulated in spare tanks for later use or recycling, thereby leveraging expensive orbital mass. Thus, one decade's garbage may be the next decade's valued resource.

6.2.2 Space Shop--Seed for Manufacturing

Earth-orbital and lunar industries must be capable of materials processing, manufacturing, and repair. These will be vital, in seed form, to Space Station operations. For example, if a furnace used to make solid state components loses power, and molten materials solidify in it, the unit may have to be torn apart, cleaned, and reassembled*. This will require a small but capable shop such as might be found onboard a naval vessel. A *space shop* should use the latest techniques in automation and robotics. It should allow materials and manufacturing specialists on Earth to use telerobots to accomplish large, complex tasks in space. The IOC space shop should support the start-up and growth of primary industry off the earth. It should lead directly to systems usable on the moon (NASA 1982).

The initial Space Station should incorporate prototypes of materials-handling units. The space shop could even make many of its own components from bulk or semifinished materials supplied from Earth, derived from salvage, or from the moon. A well targeted program might lead rapidly to the in-space demonstration of bulk material processing. Target processes should leverage lift capacity of the Space Transportation System, and extend industrial skills to space. A space shop could use a CAD/CAM database developed for the Space Station program.

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* See design team study by General Electric.

Advanced automation is affecting manufacturing (OTA 1984a) and our living and work places (NRC 1983). How we obtain basic engineering materials is changing profoundly. For example, automation has introduced large improvements in the specificity and speed of analytical chemical instrumentation used for industry and research (McLafferty 1984). Unit chemical and physical processes are increasingly controlled by advanced automated techniques. Many terrestrial procedures will be applicable to processing in space. Techniques developed originally for processing and manufacturing in space will find applications on Earth.

Development of small industrial facilities in space can quickly lay the groundwork for aggressive growth in low-Earth orbit (LEO), on the moon, and beyond. Earth-approaching asteroids, Mars, and its moons will become more accessible, given a growing industrial system of production in LEO and in cis-lunar space. Even the IOC Space Station could start and force this critical growth in basic industrial capabilities off Earth.

6.2.3 The Role of the Moon

The moon offers many useful resources for a growing space system. Many people consider the moon important to our national space program (OTA, 1984b). The United States has operational experience derived from Apollo, and detailed knowledge of lunar materials and geochemistry. Since the moon is airless and much smaller than the Earth, the machinery needed to launch useful quantities of materials from its surface can be relatively small and simple. It can be a source of materials to use in orbit about Earth, for lunar facilities, and in deep space. Soils for shielding, glass and metals for structures, and oxygen for propellants are only a few of the many possible products. It may be advantageous to construct large solar power stations on the moon's surface, using local materials, to supply power via microwaves to users on the moon, in space (facilities and transports), in LEO, or perhaps even on Earth.

Small manufacturing units (materials gathering, beneficiating, thermal and physical processors, chemical processors, flexible production systems, and warehousing and transfer systems) will extend the automation and robotics features of the Space Station to encompass most significant functions of industry on Earth (NASA, 1982). There are many common factors among the equipment and procedures needed to support human life and industry in Earth orbit, in lunar orbit, or on the moon itself. At the very least, the Space Station must not be designed to preclude the use of lunar materials or delay access to them. Lunar industries will eventually enable major explorations, for example, of the asteroids, Mars and its moons.

The Space Station should be designed from the first to enable incremental growth from LEO to the lunar surface. *Critical systems* (habitation units, materials processing units, transfer vehicles, etc.) *must be designed to allow operations around and on the moon with minimal reworking.* Modules should be compatible with operation in one-sixth gravity and with lunar landings. From the first, the Space Station design should allow for the use of lunar-derived materials in logistics support, safing, and expansion. For example, a manned Space Station element in geosynchronous orbit should accept radiation shields derived from lunar materials. Lunar materials can be returned to LEO using aerobraking. There they could be incorporated into elements of the Space Station and also leverage the uplift effectiveness of Earth-to-orbit transport systems. Orbital transfer vehicles must be designed to support missions to low orbit about the moon.

6.3 A CONTINUUM IN *SOCIETY*

The Space Station represents more than a continued and expanding presence in space. It will catalyze a wide range of Earth-based activities over a long period, activities that affect technology, management, and society as a whole.

6.3.1 R&D Relationships

Until now, space research and development has been considered separately from terrestrial R&D. But the concept of a continuum will have to be applied in this area

also. The Space Station should be designed from the start to absorb, as much as possible, advanced off-the-shelf Earth-developed hardware and procedures. It will be decades before the Space Station primarily uses technology developed in space for use in space. When this happens, humankind will truly have outgrown Earth's confines. Paradoxically, these events will be hastened by designing the IOC to incorporate advancing terrestrial developments with minimal adaptation. This was noted in the Executive Summary.

NASA in the 1980s exists in much different national and world contexts than in the 1960s. In 1964 the NASA budget of 6.5 billion dollars controlled over one-half of the government and private R&D of the United States. NASA and DoD certainly dominated national and world activities in these areas. NASA personnel were experts in most of the nation's technical capabilities. They were experienced in virtually all segments of the engineering and scientific world. NASA could afford to rework and create advanced technologies and systems to meet national space goals.

Twenty years later, in part due to NASA's successes and to the dispersal of many NASA and DoD workers to other segments of the national economy, NASA R&D is small compared to the U.S. expenditure in 1983 of over 93 billion dollars by government and private organizations. On the average, approximately half the profits of major U.S. industrial corporations are spent on R&D. Worldwide R&D spending is probably two to three times greater still and growing.

The computer industry creates new technologies so rapidly that NASA has not been able to allocate enough resources to employ state-of-the-art computer systems in space. NASA leads in only two restricted areas of computer science--massive aerodynamic calculations and highly reliable aircraft control systems. Even DoD cannot sustain state-of-the-art equipment comparable in overall performance to that available to the worldwide communications and computer industries. Thus to expedite development of the Space Station, NASA must encourage the maximum direct utilization in space of technologies developed for terrestrial markets.

Debate over "people versus machines" in space has overlooked a critical point. Since current technology serves the needs of people, a totally machine-based space program would require the complete reworking of those technologies. Conversely, "man-rated" space laboratories could be designed to accept a far wider range of terrestrial devices with minimal additional development. The Space Station can be intentionally designed to accept increasing flows of terrestrial technologies.

Designing space systems to use new terrestrial products will simplify acquisition of state-of-the-art systems in space and promote faster development of devices and systems. A wider range of people will become familiar with space operations, and those operations will be more vigorously explored and exploited outside NASA.

Space offers more than access to vacuum and very low gravity. As facilities grow, greater control will be provided over almost all basic physical conditions than is possible on Earth. Research and development in space will grow in scope, accelerated by cheaper transport to space, decreasing costs of operating space facilities, and the needs of burgeoning worldwide R&D. The Space Station should be designed to encourage this growth.

6.3.2 Advanced Machines and People

If space ventures play an expanding role in the world economy, space systems should not be designed just as pieces of hardware to perform particular tasks. Rather, they should be viewed as part of a process to eventually move much human activity permanently off Earth. Such ventures will call for new approaches in management and new uses of machines.

Engineering Styles

A question frequently raised about technological problems is "If we can go to the moon why can't we...?" The usual answer is that we do not have the resources to attack a wide range of problems at such an intense level. Apollo was the largest human-intensive systems effort in this century. It required, for several years, approximately half the nation's research and development personnel.

A return to the moon would be a far smaller effort today. This is not simply because we have already been there, because we now have the shuttle, or even because the Space Station could stage lunar missions. It is also because we have new engineering styles with far greater capabilities.

The world is realizing that new, computer-intensive methods can be used to speed engineering projects and permit people in service activities to operate far more efficiently. The National Research Council endorses the use of the Space Station program to encourage development of nationwide protocols for coordinating design, development and manufacturing of products as complex as Space Station (NRC, 1984b).

Our present transition from strictly human to computer-aided teams involves major changes in how people organize themselves and attack problems. Traditional large engineering projects require strictly organized hierarchies. Generally, most workers do not gain deep understanding of an overall project, experiment with the conceptual design, or influence more than a restricted area of the activity. In the near future, however, extensive access need not be restricted to small groups at the top. NASA could promote tools of engineering communications and design that would directly connect designers, builders, and users to the complete process. Such new control of information may be as basic to human advancement as was the 19th century introduction of mass production.

Nearly paperless and widely accessible systems would reduce costs and shorten times to completion of complex projects. They would contain detailed documentation of development stages. More important, however, they would open complex projects to a far greater pool of innovative thinking and knowledge throughout the nation.

It should not be assumed that current man-machine interface techniques, developments in machine intelligence, human factors engineering principles, and social science maxims could adequately support such large, sophisticated and dynamic systems. Technology advancement is needed to develop better techniques for letting people interact with whole systems. Man-machine science must be multidisciplinary.

Expanding the NASA Charter to Demonstrate Advancing Service Automation on Earth

In modern America, less than 20 percent of the population and cash flow is even indirectly associated with materials industry activities. Most Americans are in the service economy. It is not unreasonable to expect that, by early in the next century, fewer than 5 percent of the people in advanced countries will work directly with materials industries.

NASA is an intensely service-oriented organization, and is the high technology component of the federal government most open to public view. Its personnel, support contractors, and research communities explore and apply advanced technology openly in highly visible missions. Thus NASA is a natural choice to lead in the demonstration of advanced automation in a service industry.

NASA could be given a charter by Congress, and additional resources, to demonstrate the application of available advanced automation hardware and systems within the federal government. Long-term goals might include increased efficiency, reduced costs, and opening of the Agency even more to the nation. NASA should encourage grants and contracts develop new conceptual tools and should evaluate and widely disseminate the results—even to other organizations of the federal government. The immediate goal of this program might be to bring NASA to the state of the art in office automation and create a *paperless NASA*.

Routine tasks (such as time keeping, travel arrangements, conferences, report dissemination, resource evaluations, spreadsheets, and message relays) would be conducted electronically. A mid-range goal could be the use in management of expert systems that could assist in resource allocation at all levels, assist in crisis management (Smith, 1984), answer external inquiries, and increase the use of machine-aided management.

These expert systems should free government and contractor personnel for more creative work.

Additional electronic tools are needed for the management and scheduling of large complex systems such as the Space Station. Much is now done by hand or via many meetings which require extensive travel. New approaches are needed for cost accounting. For example, overhead allocations for some systems are based on man-hours (labor) even as labor involvement is approaching zero. Advanced computer management aids would have constantly changing world models and conduct natural language dialogues.

The Los Alamos National Laboratory is developing a multi-functional, integrated information system (INFORM). Over 1,600 employees use electronic mail, a budget system, an organizational directory (on-line, up-to-date telephone book), a bulletin board, an electronic authorization system (limiting access to those designated), and travel planning aids. The system has already eliminated much paperwork, decreased the time needed to obtain information or approvals, and promises to enhance the quality and quantity of information available for study and automated analysis.

Applying even more ambitious advanced service industry automation to NASA will directly advance automation of the Space Station. All such activities will *expedite the transfer of major NASA activities to space* over a period of time.

Human Factors and High Technology

Human factors will be a critical concern in designing automation and robotics for the Space Station. Interactions between complex machines and their human operators can be very important. In some situations (i.e., in nuclear power plants and space stations), lapses can be catastrophic.

There are three major problems in human/machine interactions:

- When failures (either human or machine) occur, human operators may have to respond very quickly.
- Human-machine interactions often promote boredom, error, and exhaustion.
- Systems developed by and optimized to an intelligent, highly motivated staff do not always remain under the control of such people. When innovators move on to new challenges, the old facilities may not be staffed as capably.

These are symptoms of inadequate design, and should be avoided through the use of human factors engineering.

New mangement problems will arise as the number and variety of people going into space grows. This trend began with the division of the astronaut corps into pilot, mission specialist, and military, industrial, and academic payload specialist categories. It is a recently declared national goal to take selected representatives of the public into orbit onboard the shuttle.

Such programs may become routine after IOC. With transportation breakthroughs, achievements in recycling and life-support autonomy, and larger scale space structures, the volume of traffic will rise. While it is premature to plan for a "tourist trade," it would be wise to consider some implications of non-astronaut visitors to the Space Station.

Untrained space visitors will require basic systems to carry more of the responsibility for safety and reliability. Space Station critical systems will not only have to withstand normal wear and tear, accidents, and degradation, but will also have to perform if damaged or misused.

Visitors will deal with many advanced machine systems not in general use. These include closed life support systems, devices for variable (including zero) perceived gravity, research facilities, or advanced language systems (especially for multinational crews). Station automation can relieve resident staff from the time-consuming responsibility of providing visitor services. Automated devices will, for example, give simple instructions, screen requests, and warn of danger. Automation and robotics capabilities that can serve and protect visitors, and also keep them from interfering with critical experiments and operations, should be part of the Space Station's design.

6.3.3 Extending Society's Reach

Commercial airlines have revolutionized global travel. Traveling 10,000 meters above the ground at 70 percent of the speed of sound, jet aircraft routinely operate safely in far more hostile conditions than will the Space Station. Air travel is so common that over 30 percent of the people in the advanced nations have flown. At any time, as much as 0.01 percent of the world's human population may be in jet aircraft. Comparing this to modes of travel only 50 years ago puts into perspective the likelihood of large-scale, routine travel to orbit. Rocket-propelled aircraft will eventually routinely operate between Earth and orbit (NRC 1984a). Transportation breakthroughs (see section 6.4) may someday make near-Earth orbits as traveled as the intercontinental airways of today.

Involvement of an ever widening variety of people in space will result in the creation of new, profitable space activities. More individuals and organizations will see space as a place with resources and potential for profit. Industry off Earth can acquire dependable solar energy at low cost. Major materials can be obtained efficiently from the moon and later the asteroids as space systems spread beyond the earth-moon system. New wealth can be created. New service industries will arise. The communication satellite industry is an example. A&R is the key that will allow the U.S. to expand its present lead in off-Earth industry.

Defense applications will play a major role in future space development, but they will usually be secret operations. There must also continue to be activities visible to the public. It is important that NASA keep our growing presence in space accessible to civilian Americans. For example, electronic communications from Earth to space can provide civilian workers opportunities to operate factories, robots, or experiments in low-Earth orbit or on the moon.

6.4 THE FUTURE: EXPECTATION VS. POSSIBILITY

We have seen that the Space Station cannot be defined as a single image in time or in space, or as a narrow community of researchers, users, and managers. No single image will ever describe it completely. The only certainty seems to be that it will not be much like anyone predicts.

Prior chapters of this study have tried to identify reasonable expectations for the year 2010. But that is not enough. The conceivable and the hypothetical should also be given some attention.

Of course, the Space Station program should not rely on speculative major breakthroughs in critical areas. Nevertheless, it should not ignore unproven technologies. For odds are great that at least one or two of the concepts discussed on the following pages will be practical within thirty years. A great society cannot afford to let breakthroughs take it by surprise.

Lift cost to low-Earth orbit is critical in deciding which space travel schemes are practical. A breakthrough in dollars-per-kilogram to LEO would bring many "science fictional" concepts within the reach of profit-minded investors.

It is reasonable to expect travel from Earth to orbit will become more routine, frequent and far less expensive than with the present version of STS. In the extreme case, one can conceive a fleet of small vehicles which could transport people and goods to LEO at only ten times the cost of the minimum energy required to move them there. That energy is about 10 Kw-Hr per kilogram. Assuming a unit cost of $.10 per Kw-Hr, this would imply a cost to orbit of 10 to 20 dollars per kilogram with the new vehicle, or only a few times the present price of transoceanic air travel.

Current trends will force advances. For instance, STS effectiveness will grow in part through increasingly automated operations, more frequent usage, evolved versions, and economies of scale. Intense debate is underway among NASA, the Air Force, and private groups concerning the use of the STS and expendable launch vehicles. Military and commercial long-range aerodynamic flight may evolve into semi-ballistic operations.

Proto-scale industrial operations in space may develop into much larger-scale activities using materials transported via shuttle excess lift capacity, or derived from space-salvaged shuttle external tanks or off-Earth sources.

Every mission of our Space Transportation System lifts over 350,000 pounds to space. This is seven times the shuttle's rated internal cargo capacity. Launch systems derived from STS can carry to orbit far greater payloads of people, components, and systems or bulk materials. Lift capacity of this magnitude can support diverse, large scale activities. Priority must be given to identifying plausible goals in space of sufficient importance that the associated traffic could itself sharply reduce the cost of Earth-to-orbit travel. Other possibilities are worth citing.

Tethered systems seem to offer a whole new generation of opportunities in space operations. The ability to exchange momentum between two co-orbiting masses, to provide gravity gradient attitude stabilization and milli-gravity work environments, and to electrodynamically apply orbital torque against the Earth's magnetic field, are all exciting concepts. Some have already been incorporated in Space Station baseline design. Others merely await experimental confirmation within the next few years. (In almost every way, tethered systems appear to benefit from advances in automation and robotics.) It would be short-sighted to preclude such new capabilities in the IOC design.

There are other examples, many of them involving advanced automation and robotics. The nation may follow the Space Station with more ambitious activities featuring utilization of *the moon and near-Earth asteroids and perhaps eventually visits to Mars.* As mentioned earlier, these endeavors may fundamentally alter our priorities, and early space infrastructure should at least not obstruct them unnecessarily.

Electronic communications and computers provide a second portal to space, one which complements travel. The present conception of the 2010 Station proposes dramatic advances in these areas. People on Earth can operate complex machinery in space, on the moon, or on asteroids. Systems may grow rapidly in space under remote control from Earth.

The ~~area of~~ *space industrialization* is ripe for breakthroughs. If there is a sudden, major demand for orbital workspace, factory volume, mass, or raw materials, will the Space Station be able to adapt quickly? Could it accommodate attachments? Unexpected new facilities? What will be the automation requirements?

Again, planners cannot *count on* breakthroughs, but they should have contingency plans that allow for them. Dr. R. Frosch (p. 95 in OTA 1984b) has suggested that machines may someday be designed to make copies of themselves, using solar power and only local materials. A few such machines placed, for example, on the moon, could increase exponentially to a large population in a short time. They could then be reprogrammed to produce other types of manufacturing systems, solar power systems, propellants, structures, other goods, and services. Exponentially growing machine systems are simply the ultimate extrapolation of industrial processes developed over the past 400 years. We cannot build such systems now, even though they are possible in principle. However, small amounts of goods and materials can be imported to the moon and combined with common lunar materials to produce a wider range of machines and goods than could be produced locally. Mass imported from Earth could be multiplied into a much larger mass of almost entirely lunar products. Effective multiplication would increase as our off-Earth skills evolve.

Another potential breakthrough that might dramatically alter the balance between pipe dream and practicality, would be advances in automated *life-support technology*, allowing substantially greater autonomy. This might vastly reduce the cost of large manned stations, manned deep-space missions, or a permanent base on the moon. This area, perhaps second only to lift cost in potential importance, will benefit strongly from progress in automation and robotics.

The Space Station and associated systems should enable us to take advantage of such opportunities.

6.5 BROADER OPPORTUNITIES AND AUTONOMY

The Space Station will be many things over time, in space, and in society. It is a means to a variety of ends, not an end in itself. Much of what we predict today will bear little resemblance to future realities. Thus we must keep broader opportunities in mind while designing a space infrastructure. It must be practical and efficient by today's standards, but be capable of adapting to significant change.

6.5.1 Recommendations for Growth

- Consider the Space Station as a means to a growing system of human activity in space.
- Planners should not have a single, specific image of the Space Station. The space infrastructure will undoubtedly
    - change dramatically with time,
    - be widely dispersed in space,
    - be interwoven with Earth society,
    - accommodate a wide range of missions and goals,
    - be strongly dependent on the success of A&R.
- With this in mind, designers should emphasize
    - flexibility,
    - use of interchangeable parts,
    - economies of scale (i.e., lowering costs over large production runs),
    - potential use of Space Station derivative modules in other ventures and locales (e.g., lunar orbit or surface, asteroids, moons of Mars),
    - potential recycling of retired space hardware, external tanks, organics, volatiles, and orbital momentum,
    - new space industrial services,
    - potential for receiving and using new resources, such as materials from the moon and beyond.
- Immediately start developing a *space shop* capability for on-site repair and even small-scale fabrication.
- Provide high-quality communication and manipulative links with Earth whereby Earth-bound personnel can access, assist, direct, and conduct complex tasks in orbit.
- The implications of involvement of a wide variety of citizens in space, by proxy or in person, should receive close scrutiny.
- NASA should be chartered to lead in the demonstration of advanced service industry automation within the federal government. It should receive extra, continuing resources to do so as it succeeds.
- Promising technologies for reducing lift transportation costs should be pursued even at some risk, since rapid progress in this area will have substantial benefits. IOC design should not preclude expansion, retrofit, use of tethers, or resupply by expendables.
- Design the IOC not only to welcome *expected technological advances* but to anticipate and be adaptable to *possible major technological breakthroughs*.

6.5.2 Recommendations Concerning Autonomy

Some degree of autonomy from Earth logistical support will be necessary. Efforts to increase autonomy will lead to augmentation of space infrastructure as a portal to new opportunities beyond Earth. To that end, the Space Station program should have the following attributes:

- Advanced automated life support techniques for semi-closed system autonomy merit substantial, reliable, long-term investment. New automated approaches should be encouraged.
- Initial capabilities to *process bulk materials* and components into other shapes, compositions and applications will help industrial concerns interested in space processing, and will also provide experience working materials in space.
- Capabilities to process materials and manufacture basic goods *for use in space* should be consistent with our growing abilities to deliver materials to orbit.

- Proto-scale capabilities for initially limited manufacturing, repair, maintenance, and upgrading of orbiting devices and facilities should be established. Problems of inventory and resupply should be analyzed with a mind toward optimized on-site autonomy.
- Space Station automation should be planned from the start to create and capitalize on use of lunar materials and mutually supportive operations in Earth orbit and on the moon.

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Chapter 7

ADVANCEMENT AND IMPLEMENTATION

7.0 RECOMMENDATIONS

The Congressional mandate anticipates tremendous potential benefits from developing automation and robotics for the Space Station, as well as the high degree of technology advancement required to achieve these benefits. The United States can regain its preeminence in industrial technology and create new concepts of manufacturing and human service via robotics. Preceding chapters have described the enormous opportunities to exploit space to achieve new knowledge, products, and services, and to help improve life on Earth.

These goals will only be fully realized if automation and robotics are adequately advanced and implemented, not only in the Initial Operational Capability (IOC) Space Station, but far beyond it as well. As described earlier, this requires a large, long-term program. The Panel makes the following major recommendations which we believe to be of the highest priority if the Space Station program is to achieve the goals set forth by Congress (from Chapter 1):

Establish management structures that ensure rapid, ongoing advancement of Automation and Robotics (A&R)

Recommendations

11. Establish management structures in NASA to ensure that
    a) the needed A&R technology advancements occur unimpeded by Space Station operational or budgetary problems.
    b) there is a strong linkage between the technology advancement program and Space Station A&R implementation activities.
    c) the goals for Space Station A&R technology advancement reflect a consideration of broader applications (including terrestrial).
    d) the A&R technology advancement and implementation activities have visibility and accountability to the highest levels of NASA and to Congress.

12. Without presuming to recommend a specific organizational structure, the Panel further suggests strongly that NASA accomplish Recommendation 11 by providing
    a) an organization, managed outside the Office of Space Station, to lead the A&R technology advancement activity.
    b) the A&R technology advancement activity with a line item no lower than a first level breakout of an Associate Administrator's budget.
    c) a second organization, administered within the Office of Space Station, charged with promoting smooth flow of capabilities from the A&R advancement activity to Space Station operation, and with conducting required prototyping and testing activities.

13. Create an external review panel consisting of experts from universities, industry, and government to
    a) conduct in-depth review of NASA A&R activities.
    b) advise NASA.
    c) present annual reports to Congress.

7.1 ACHIEVEMENT OF A&R BENEFITS

To achieve the benefits of automation and robotics for the Space Station, NASA must perform the following four basic steps:

Step 1 - Provide the advancing technology base.

Step 2 - Conduct early demonstrations (ground and flight) of key new capabilities.

Step 3 - Develop and test prototypes.

Step 4 - Achieve operational implementation.

These steps have different time frames and involve different degrees of technological risk. Under the financial and time constraints of the Space Station program, how should time and money be distributed among them? For example, the first step has a high technological risk, since only a fraction of the approaches investigated ultimately lead to operational devices. And time frames can be very long, 10 to 20 years in many cases; technology advancement activities begun now will be directed primarily toward post-IOC implementation. Yet, these activities are essential to future operations; without them, the Space Station will not achieve its full capabilities. A&R experts must be funded to pursue new ideas to meet long-range goals, and chartered to develop and implement advanced A&R on the Space Station.

At the opposite end of the advancement sequence, the implementation activities in the fourth step have high public visibility, involve low risk, and must meet rigid time schedules. The manager of the Space Station program must ensure that the Station is built on schedule and works satisfactorily.

NASA must create A&R management structures which makes certain that

- All four steps of the effort are pursued vigorously.
- Adequate interaction is developed among the four steps.
- The quality of the effort is maintained at a high level.
- The Congressional mandate is met.

The Panel believes that the implementation and deployment of A&R is principally the concern of the Office of Space Station but will be driven by the capabilities which arise from fundamental technology advancement. Thus, this chapter primarily addresses organizational characteristics associated with the first three steps of A&R activity.

7.1.1 Ensuring the Achievement of A&R Technology Advancement

A&R Organizational Considerations

Previous chapters have identified many specific applications of automation and robotics for the Space Station program. Realization of most of these will depend upon an active, long-term NASA program to advance the state of the art of A&R technology. Cost estimates for the technology advancement program, including the concept demonstration stage, are presented in Chapters 1, 3 and 4.

To carry out the technology advancement program, NASA must provide the following:

- An adequate, stable budget.
- A focus on long range activities and freedom from daily pressures of implementation.
- Goal-setting mechanisms that give a strong voice to both the implementation organization of the Space Station effort and the A&R technology experts.
- A mixture of in-house and externally funded activities.

The technology advancement activities will call for highly trained personnel. It will take several years to build the needed level of staffing, both internal and external. Personnel with the appropriate training are in high demand, and stable, adequate funding is necessary to keep these people. It is, therefore, very important that funding for technology advancement be maintained, regardless of delays or costs in Space Station implementation. The funding patterns shown in Chapter 1 reflect this.

Effective A&R for the Space Station requires long-term fundamental studies directed principally toward post-IOC capabilities. The time frame of these studies clearly goes far beyond IOC construction and implementation. The implementation organizations and the technology advancement organization should participate in the development of long-range goals but not in coordination of day to day activities. While close attention must be paid to Space Station Office needs, technologists should be free to concentrate on leading A&R concepts without being directly involved in the daily pressures of implementation and deployment. The A&R implementation (Recommendation 12c) and the A&R technology advancement (Recommendation 12a) organizations can independently track Space Station activities to identify new applications.

A key activity in Step 1 will be to chart a course and plan the utilization of resources. In setting long-range goals, all organizations of the Space Station effort should indicate specifically what they want and need automation and robotics to do. The A&R technology advancement organization must then identify and study the critical areas necessary to achieve these goals. The study programs should involve both internal and external work.

NASA should build a strong internal capability in A&R. It should maintain contact with industries and universities and evaluate A&R technologies so that NASA can be a "smart buyer" and a "smart patron" of external technology. It should be able to integrate component technologies into demonstration systems and support R&D and flight operation organizations.

NASA must also invest heavily in external technology advancement. Severe manpower shortages in important technical areas make acquisition of qualified staff difficult. Many critical capabilities in both universities and industry are available only through external contracts. NASA should consider establishing several technology advancement centers at major universities.

The technology advancement organization must also carry out space demonstrations of principal technologies. Such demonstrations will not be expected to space-qualify equipment but will be used primarily to illustrate new A&R concepts. They might also be an excellent method of encouraging technical exchange with other organizations in the Space Station effort.

Suggested Organizational Constraints

The Panel believes that the key to ensuring the rapid and ongoing advancement of A&R technology for space applications (Step 1) lies in assigning this responsibility to a single organization within NASA. This A&R technology advancement organization should also direct the concept demonstrations (Step 2). The Panel believes strongly that this fundamental technology advancement should be separated at a high level of management from prototyping, testing and implementation. Otherwise, there is a danger that resources for technology advancement could be redirected toward high-pressure short-term goals. This would delay advancements in key technologies. In particular, the Panel believes that the responsibility for A&R technology advancement should lie outside the Office of Space Station. These considerations give rise to Recommendation 12a.

The Panel considered several models the technology advancement organization might use to manage contracts. One is the Defense Advanced Research Projects Agency (DARPA) in which a few highly qualified technical people define major program areas, accept and review proposals, and make contract decisions. The individual military services bring ideas to DARPA for funding of work to be conducted jointly. This program has yielded important results in machine vision, artificial intelligence, expert systems, microelectronics, and new computer architectures. Yet DARPA itself does not administer its contracts; the services award and manage them.

A similar model could work well for NASA. A lead center could be assigned to work with the A&R technology advancement organization to provide both technical expertise and contracting services. This will allow NASA to put the technology advancement organization into operation quickly and with a minimum of overhead.

A lead center can also serve as a repository for facilities to be shared by NASA and its contractors. For example, a knowledge engineering laboratory would be extremely useful to both NASA and a broad range of university and industry contractors. The laboratory would contain several knowledge bases and provide computer simulations of key problem domains. Such knowledge bases and simulations can take many man-years to develop. Having them in a central, shared facility can save a great deal of effort, and also provide a common base for comparing techniques developed by different investigators.

Shared facilities will also be necessary in areas such as massively parallel computer systems, computer aided design (CAD) databases of hardware, and complete dynamic simulations of the Space Station. The centralized facilities must be physically accessible to many users. Workers in the wider A&R community must be able to access the centralized facilities and each other via a NASA SPAN or ARPANET.

7.1.2 Ensuring Linkage between A&R Technology Advancement and Implementation

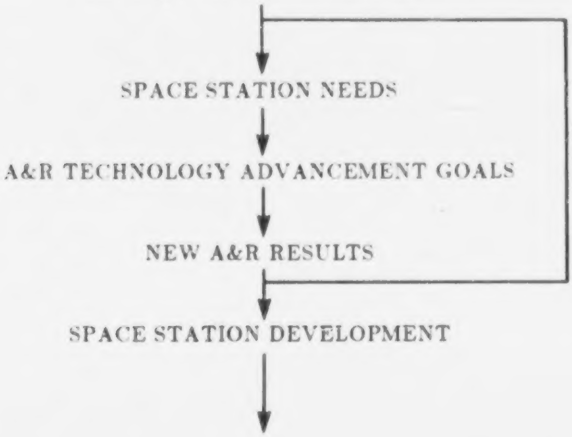
It would be preferable to have the A&R technology advancement and the implementation of advanced systems in the Space Station be conducted by separate organizations. However, they must cooperate in setting overall goals, understanding the potentials of new concepts, and in bringing suitable new concepts into the operation of the Space Station.

Coupling Advancement and Implementation

A&R technology advancement activities can be closely coupled to the Space Station's needs by an implementation organization in the Office of Space Station. Exhibit I depicts the desired situation.

Exhibit I

Relationships between new A&R technology advancement and implementation activities



The A&R technology advancement organization should set joint goals with other NASA entities. All major Space Station development and operations groups should have a strong voice in setting these goals. Also, reports from the external review panel (see section 7.2) should weigh heavily in planning activities. The Space Station implementers do not need to concern themselves with the daily activities of the A&R technology advancement organization. They must, however, participate in the general technology advancement. Frequent joint technical progress reviews will ensure mutual awareness of activities and promote technical exchange.

Ensuring A&R Technology Insertion

There must be a mechanism for the efficient flow of advanced technology into Space Station operations. A large corporation typically has a research laboratory, an engineering department, and a manufacturing department. The engineering department often serves as an intermediary between research and manufacturing. The Panel suggests a similar arrangement in the Space Station program, to be administered by the Office of Space Station. This gives rise to Recommendation 12c.

The most practical ideas must be extracted from the advancing technologies. Someone must assist the researchers in maintaining practical goals, and help those actually building and operating the Space Station learn to understand and use the new technologies. The educational process is particularly critical.

In the categories of technology development described earlier, Step 1 is the initial creation, performed by scientists and research engineers, and Step 4 is the ultimate implementation step performed by Space Station construction engineers. In between, advanced development engineers will be responsible for the space demonstrations in Step 3. The concept demonstrations of Step 2 must be joint projects between research engineers and advanced development engineers. Such projects are also an excellent way to pass in-depth knowledge of new A&R concepts to those who will be responsible for their further development. Similarly, involving the Space Station construction engineers in prototype testing (ground, aircraft, and shuttle flights) will give them the detailed knowledge they need to implement new A&R capabilities.

A matrix relationship between the two new organizations would encourage greater flexibility in moving new ideas into operation. Developers could temporarily move into the advanced development arena to participate in prototyping and space-qualifying tests. Consider, for example, the development of an Astronaut's Apprentice. This project would begin with an autonomous robot *go-fer* on the IOC using off-the-shelf technology. The project would evolve into an autonomous system for operation and repair of the core Space Station. This would eventually leave the crew almost entirely free to concentrate on user and payload functions (see Appendix 2-A).

7.1.3 Ensuring Additional Responsibility for Broader Applications

A major aim of the Congressional mandate is that A&R technology developments sponsored by the Space Station program should benefit the nation's civilian economy through advances in manufacturing and service industries. Thus, while the A&R technology base will primarily benefit the Space Station, the technology advancement organization must consider non-NASA applications in its planning. It must also see to it that the advancements reach the civilian economy.

The Space Station program can promote the use of terrestrial A&R in space by designing the evolving Space Station to readily accommodate terrestrial technologies. Increasing A&R technology transfer between space and Earth applications should be encouraged throughout the program.

7.1.4 Ensuring Visibility and Accountability

Congress has mandated the accelerated use of automation and robotics in the Space Station. Thus, NASA activity in these areas should be both visible and accountable to the highest levels of NASA, to Congress, and to the nation as a whole. This will help establish the importance of A&R technologies and encourage broad participation in their advancement. It will also encourage implementation of the technologies within NASA, and their transfer to private industry. The accountability at high levels should provide budgetary stability for the technology advancement activity.

The Panel suggests that placing the budget for the A&R activity at a prominent high level in NASA's budget (as indicated in Recommendation 12b) is an effective way to ensure this visibility and accountability.

7.2 EXTERNAL REVIEW PANEL

The automation and robotics program must be maintained as a top quality activity. To ensure this, an external review panel is recommended, to be drawn from industry, academia, and government. This panel would advise the government and the nation on the best near- and long-term A&R goals and on how to achieve them. The panel activities can also encourage other national communities to help bring advanced A&R to use in space and on Earth. It may be necessary to encourage the growth of new A&R communities.

7.2.1 Purpose and Function

The external review panel should establish goals and priorities for both Space Station and national interests. Through its committee selections, the review panel should ensure broad exposure in industrial, academic, and governmental sectors and the subsequent transfer of knowledge.

The review panel should perform the following minimum functions:

- Conduct an annual peer review of A&R research and technology to maintain the high quality of the program.
- Actively advise NASA on A&R technology advancements pertinent to Space Station. In particular, the panel should review and expand the Space Station A&R implementation plan.
- Annually report to Congress on technology advancements in automation and robotics.

7.2.2 Implementation

Several models exist for the external review panel, including panels operated by the National Research Council (NRC), the Lunar and Planetary Review Panel operated for NASA, and panels created by professional societies.

For example, NRC's advisory Space Science Board whose purpose is to counsel the federal government on goals and priorities for space science, appoints committees to prepare strategy reports. Their findings and recommendations are directed principally to NASA management and, through them, to the Executive branch of the government. The Board also communicates its recommendations to Congress through letters and individual testimony, and makes its reports available to the public on request. The main drawback of this approach is that NRC panels typically meet too infrequently to track and advise on rapidly changing technologies.

Other implementation options should be considered. For example, since the review panel would be concerned primarily with technology issues, it could be organized within the National Academy of Engineering. Another approach might be to establish it through joint sponsorship by universities, industries, and governmental agencies (such as NASA, DARPA, and the National Bureau of Standards) that have a strong interest in A&R technology. A properly constituted external review panel can vitalize the advancement of automation and robotics within NASA and link NASA to the relevant national communities.

7.3 A CHALLENGE

The Automation and Robotics Panel concludes that the United States Congress was correct to broaden the challenges assigned to NASA, especially in its approach to advanced A&R technologies.

NASA is world renowned for its accomplishments in space. Advanced automation and robotics can make the Space Station, in particular, into a toolset for America to use for growth beyond the Earth. Space Station automation and robotics will also directly advance technologies and procedures that benefit industries and individuals here at home.

Can NASA and its affiliates in the Space Station program meet these new challenges? If so, the nation's goals and capabilities, on and off Earth, will expand, last longer, and involve more people. These groups face a demanding challenge during the short definition portion (phase B) of the Space Station program. The nation should carefully scrutinize their accomplishments. They are defining the tools for our permanent growth beyond Earth. These tools should be versatile, cost-effective, safe, and supportive of the highest creativity.

GLOSSARY

Ada - High-level programming language developed by the U.S. Department of Defense for use in embedded computer systems.

ARPANET - A network linking computers sponsored by the Defense Advanced Research Projects Agency (DARPA).

Artificial Intelligence (AI) - A discipline devoted to developing and applying computers to produce intelligent behavior.

Autonomous - Capable of independent action.

Backtracking - Returning to an earlier point in a search.

Backward chaining - A form of reasoning that works backward from a goal toward the required conditions.

Bottom-up control structure - A problem-solving approach that reasons forward from current or initial conditions.

C - High-level programming language developed at Bell (AT&T Information Systems) Laboratories for systems programming.

Cis-lunar - Between the earth and the moon.

Cognition - An intellectual process for gaining knowledge about perceptions or ideas.

Common sense reasoning - Low-level reasoning based on experience.

Computer architecture - The way in which computational elements are connected to perform an overall function.

Computer graphics - Visual representations generated by a computer.

Computer network - An interconnected set of communicating computers.

Computer vision - Perception by a computer based on visual sensory input.

Concurrent programming - Allows multiple processes to occur simultaneously.

Core network - Space Station computer capable of handling basic survival and housekeeping functions.

Cryogen - Liquid that boils at a very low temperature (typically less than 110 K) at atmospheric pressure.

Database - An organized collection of data.

Database management system (DBMS) - A system designed to store and retrieve information.

Data-driven - A forward reasoning, bottom-up approach to problem solving.

Data structure - The form in which data in stored in a computer.

Debugging - Correcting errors in a system or computer program.

Decision support system (DSS) - Computer program that provides advice or analysis aimed at helping a professional make complex decisions.

Deductive reasoning - Working from premises to a conclusion.

Default value - A value to be used when the actual value is unknown.

Distributed System - Many communicating functional elements at several locations.

Editor - A computer program used to enter and correct text.

Emulate - Perform like another system.

End effector - The tool or "hand" at the end of a robotic arm.

Ergonomics - The study of human factors in the workplace.

Expert system - A computer program that uses knowledge and reasoning techniques to generate advice and make limited decisions normally requiring the abilities of a highly trained person.

Fail operational - A system which continues to operate following failure of subsystem(s).

Fail safe - A system which remains safe following subsystem(s) failure.

Fiber optics - Thin glass fibers used to link optical communication systems.

Fiducial point - Mark used for reference or measurement by an optical instrument.

Fifth Generation Computer - A non-Von Neumann, intelligent, parallel processing form of computer now being developed in Japan.

Gigabit - One billion bits.

Go-fer - A robot capable of responding to simple requests for parts and materials.

Heads-up display - A simulated visual display which can be viewed while looking straight ahead and changed by movements of the operator's head.

Hook - Software that serves mainly to allow later additions or extensions to a system.

Hybrid (teleoperator-robot) system - See telerobot.

Knowledge bases - A database used in artificial intelligence applications, consists of facts, inferences, and procedures required to solve a problem through reasoning.

Knowledge engineering - AI use of knowledge bases to solve problems.

Knowledge representation - The form of data structure used to organize the knowledge required to solve a problem.

LISP - List Processing Language, a computer language widely used in AI applications.

Local area network - A network of computers and other elements that is geographically restricted to within a small area such as a single building.

Machine vision - See computer vision.

Macromodular - Consisting of separate large, independent units.

Menu - Listing of the current options available to a system operator.

Micromodular - Made up of simple building blocks.

Natural language interface - Communicating with a computer using human language.

Node - An element in a network.

Object-oriented programming - A programming approach focused on objects that communicate by passing messages.

Operational network - Space Station computer network capable of handling user needs over and above core needs.

Orthographic representation - Perpendicular projection of a three-dimensional object on a two-dimensional surface.

Parallel processing - Simultaneous processing of inputs.

Pattern matching - Comparing inputs to images or templates in a database.

Perception - The process of classifying data into predetermined categories.

Portability - The ease with which a computer program developed in one programming environment can be transferred to another.

Programming environment - The total setup used to develop programs, including languages, editors and other programming tools.

PROLOG - Programming in Logic, a logic-oriented AI language.

Protocol - Set of conventions governing the format and timing of data exchange between communicating systems.

Real-time system - System that controls an ongoing process and gathers inputs and produces outputs at the times required for effective control.

Retrofit - To add hardware to an operational system or structure.

Scar - Hardware that serves mainly to allow later additions or extensions to the system.

Sensor fusion - Combining information from one or more sensor.

Signal processing - Analysis of real-time data from sensors.

Software tool - A program used maily in the development of other programs.

Space-qualified hardware - Elements certified as capable of operating in an unprotected space environment.

Speech recognition - Recognition by a computer of spoken words.

Speech synthesis - Development of speech from text or other representations.

Symbolic processing - Use of logic and reasoning to deal with relationships between non-numeric objects.

Symbolic programming - Writing of programs to perform symbolic processing.

Telerobot - An abbreviation of hybrid teleoperator/robot, a device capable of some independent (autonomous) operation but generally requiring remote operator control for most tasks.

Teleoperator - A manipulator that can be controlled continuously and in detail by a human operator, either remotely or "hands on."

Telepresence - Making the remote operator of a system feel as if he or she were actually present in the workplace through sensory inputs and feedback.

Terabyte - One million megabytes, 10^{12} bytes.

Top-down approach - A goal-directed approach to problem-solving.

Von Neumann architecture - Standard computer architecture based on stored programs and sequential processing.

World model - A representation of the current situation.

ACRONYMS AND ABBREVIATIONS

A&R	Automation and Robotics
AI	Artificial Intelligence
ANSI	American National Standards Committee
ARP	Automation and Robotics Panel
ASCII	American Standard Code for Information Interchange
ATAC	Advanced Technology Advisory Committee
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAI	Computer Aided Instruction

CAM	Computer Aided Manufacturing
CAT	A Small, Furry Animal
DARPA	Defense Advanced Research Projects Agency
ECLSS	Environmental Control and Life Support System
EMU	Extravehicular Mobility Unit
ET	External tank of the STS
EVA	Extravehicular Activity
GaAs	Gallium Arsenide
GEO	Geosynchronous Earth Orbit
GPS	Global Positioning System
H/W	Hardware
IOC	Initial Operational Capability
IVA	Intravehicular Activity
LEO	Low-Earth Orbit
NAE	National Academy of Engineering
NAS	National Academy of Sciences
NBS	National Bureau of Standards
NDE	Non-Destructive Evaluation
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OAST	NASA Office of Aeronautics and Space Technology
OMV	Orbital Maneuvering Vehicle
OSS	NASA Office of Space Science and Applications
OTA	Office of Technology Assessment
OTV	Orbital Transfer Vehicle
PC	Personal Computer
RMS	Remote Manipulator System
ROV	Remotely Operated Vehicle
RRM	Replaceable Reconfigurable Module
SPAN	Scientific Program Access Network
STS	Space Transportation System
S/W	Software
VHSIC	Very High Speed Integrated Circuit
VLSI	Very Large Scale Integration

NASA Technical Memorandum 87566

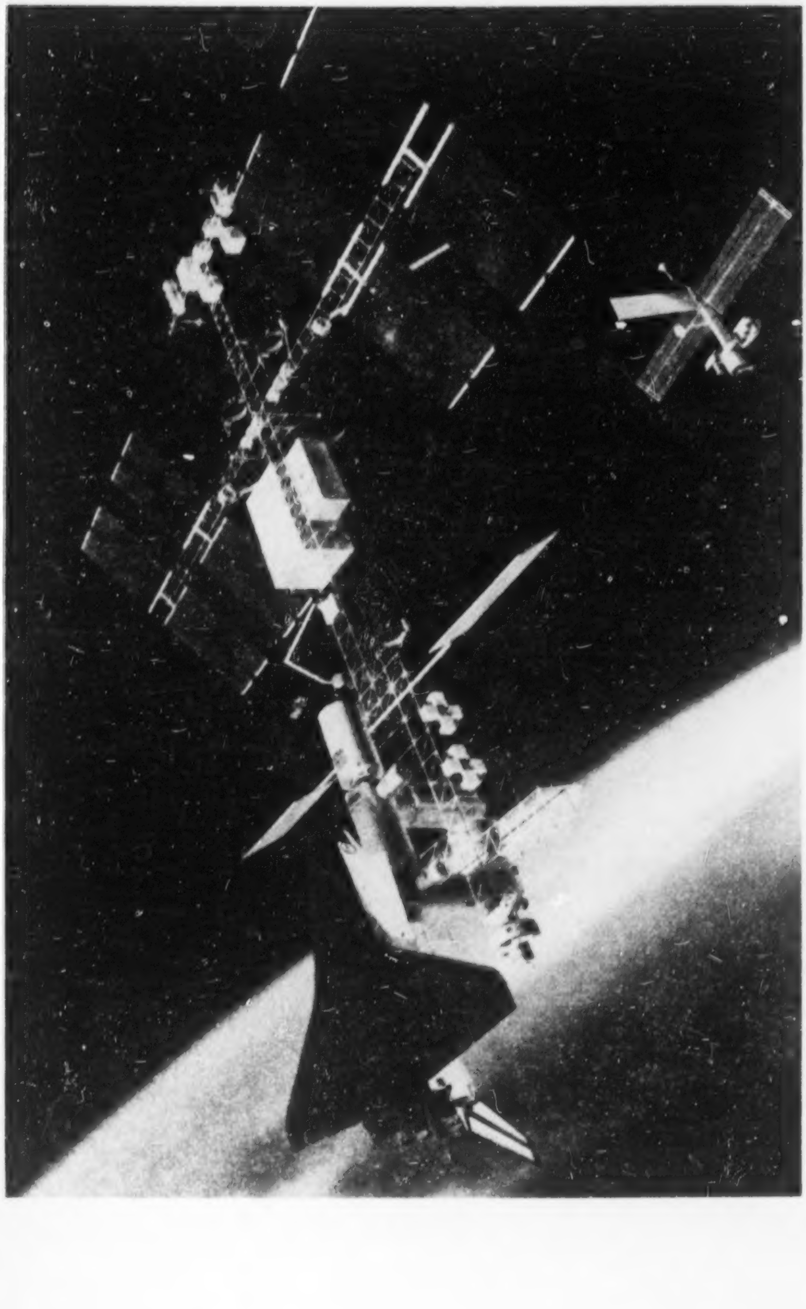
Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy

Volume I — Executive Overview

Advanced Technology Advisory Committee
National Aeronautics and Space Administration

Submitted to the
United States Congress
April 1, 1985

NASA
National Aeronautics and
Space Administration



Synopsis

We are at the beginning of a new era in space. As we move into the second 25 years of the U.S. space program, we will meet significant challenges. This era will bring a major thrust in the commercial use of space. And, with the Space Station, it will bring the achievement of a permanent American presence.

The development of the Space Station offers us a chance both to advance the technology of automation and robotics, as proposed by Congress, and to put that technology to use. The use of advanced automation and robotics technology in the Space Station would greatly enhance its capabilities. And the Space Station would thereby provide a logical driving force for a new generation of machine intelligence and robotics technology, built on recent advances in artificial intelligence, robotics, computer science, and microelectronics.

The advances in automation and robotics stimulated by the Space Station Program could benefit the U.S. in many ways, notably,

- Increased productivity in space for commerce and science
- Increased productivity throughout the U.S. economy as the new technology is transferred back to Earth-based industries
- Preservation of U.S. leadership both in space and at the cutting edge of technology in general

To create a new generation of technology, NASA will have to overcome difficult obstacles. But the Advanced Technology Advisory Committee believes that NASA can achieve this goal.

The blue planet.

Preface

In response to Public Law 98-371, dated July 18, 1984, the NASA Advanced Technology Advisory Committee has studied automation and robotics for use in the Space Station and prepared this report to the House and Senate Committees on Appropriations. The study has drawn on work by groups both within NASA and outside NASA, in the academic and industrial communities.

The report is divided into two volumes.

The Executive Overview, Volume I (this document), presents the major findings of the study and recommends to NASA principles for advancing automation and robotics technologies for the benefit of the Space Station and of the U.S. economy in general.

The Technical Report, Volume II, provides background information on automation and robotics technologies and their potential and documents the following:

- The relevant aspects of Space Station design
- Representative examples of automation and robotics applications
- The state of the technology and advances needed
- Considerations for technology transfer to U.S. industry and for space commercialization

This report is referenced in the request for proposals for definition and preliminary design of the Space Station. Volume II in particular provides guidance for prospective Space Station contractors to direct their efforts toward a planned advance in these technologies.

In response to an agreement with the Senate Appropriations Committee in April 1984, NASA funded and managed a number of studies in the general area of automation and robotics. These studies were done by academic and industrial specialists working in the field, and they provided important insight to the Advanced Technology Advisory Committee.

An Automation and Robotics Panel, led by the California Space Institute, prepared the report "Automation and Robotics for the National Space Program." Five aerospace firms conducted studies of critical issues (synopsized in this volume in the section on case studies). Further, SRI International studied the general state of the technology and areas in which research is needed. The documentation of all of these studies is referenced and should be read in conjunction with this report.

Introduction

The first 25 years of the U.S. space program have been exciting and successful and have advanced the **exploration** of space in countless ways. However, new times bring new challenges, and in coming years the U.S. space program must:

- Expand its focus to include commerce as well as exploration
- Assure effective utilization of resources
- Meet international competition
- Establish a permanent manned presence in space

These challenges characterize a new era, one focused on meeting the needs of commercial **customers**, **scientists**, and other **users** of space.

There are two keys to success in meeting the challenges at hand. One is to develop and use the "right" technology; the other is to function as efficiently and effectively as possible, both within the Government and in dealings with the private sector.

Congress has seen the wisdom of developing a new generation of general-purpose automation and robotics technology. Such a general-purpose technology would be efficient and flexible enough to meet needs as yet unspecified. Therefore, Congress has given NASA a mandate to advance the state of the art in automation and robotics for the benefit not only of the Space Station but also of the U.S. economy as a whole.

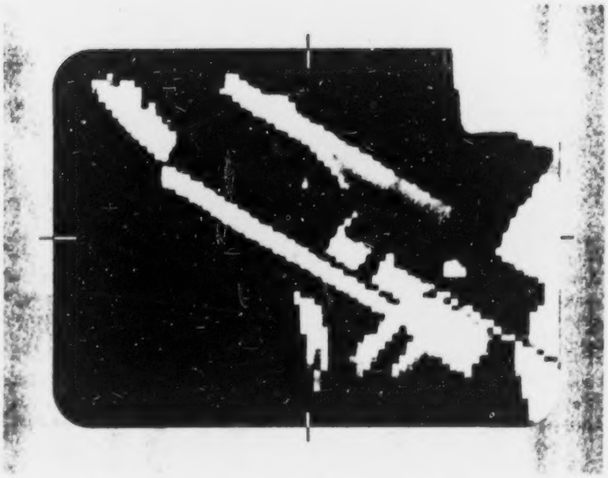
The next 25 years of the U.S. space program promise to be more exciting and productive than the first 25, and the exploitation of advanced automation and robotics offers a means for the United States to meet the challenges of this era.

Automation, Robotics, and the Congressional Mandate

The United States Congress became convinced that the Space Station Program could be a logical user and a highly visible stimulator of new technological advances. A conference committee report suggested that NASA should examine existing systems *"whose potential for enhancing automation and robotics technologies appears promising."* The report also expressed the expectation that such technologies might not only *"increase the efficiency of the station itself"* but also *"enhance the Nation's scientific and technical base leading to more productive industries here on Earth."*

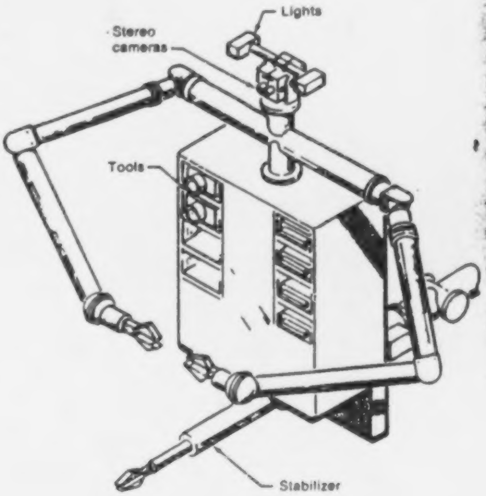
In April 1984, the Senate Appropriations Committee and NASA agreed to a congressionally sponsored study to produce an "Automation Report" for the Space Station. To that end, Public Law 98-371, dated July 18, 1984, and titled "National Aeronautics and Space Administration Research and Development, 98 Stat. 1227, Research and Program Management Report," provides that

> *The Administrator shall establish an Advanced Technology Advisory Committee in conjunction with NASA's Space Station program and that the Committee shall prepare a report by April 1, 1985, identifying specific space station systems which advance automation and robotics technologies, not in use in existing spacecraft, and that the development of such systems shall be estimated to cost no less than 10 per centum of the total Space Station costs.*



Computer or machine vision will permit automatic recognition of objects such as a Shuttle coming in to dock.

Sophisticated manipulators can approach the dexterity of humans for specialized tasks.



As a result of its study, the Advanced Technology Advisory Committee believes that a key element of the "right" technology for the Space Station era is extensive use of advanced general-purpose automation and robotics. This could include many systems and devices (such as computer vision, expert systems, and dextrous manipulators) that have been made possible by recent advances in artificial intelligence, robotics, computer science, and microelectronics.

The exciting potential of automation and robotics, outlined in this document, can be realized only when the systems and devices are actually implemented in the Space Station. Such an implementation must follow an overall plan and be carefully integrated with station systems and operations. The details of the implementation in the initial station would be established during the definition and preliminary design phase. NASA should also produce during this phase a plan and requirements for additional implementation of automation and robotics in later versions of the station.

Properly focused reliance on automation and robotics in the Space Station could free humans in space for the roles they fill best. That is, using their intelligence to perceive, to understand, to redefine continually what needs to be done on the basis of what has been learned, to take advantage of unforeseen opportunities, to solve unexpected problems, to save a mission (occasionally), to supervise machines, to adapt with minimal reprograming, and to acquire, integrate, and interpret multisensory data to meet mission needs.

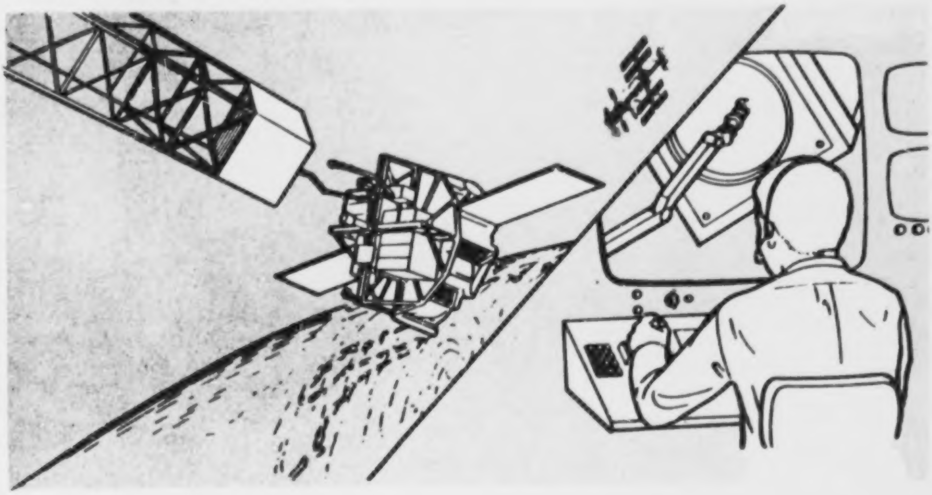
Automation and robotics could be an important factor whether the Space Station is initially inhabited or only tended by humans at intervals with permanent habitation deferred for several years.

Automation in spacecraft has been important from the days of the earliest satellites. Current space systems incorporate a high degree of automation, and plans for the Space Station have always called for the use of mobile remote manipulators and advanced control devices. However, the demands of a multipurpose facility like the Space Station are so great that major advances into the challenging territory of adaptable and general-purpose automation and robotics should be made if the full potential of the Space Station is to be realized.

The advances that will be required could come about in three ways. In some areas, NASA can be the prime mover in the development and application of new technology. In other areas, NASA can adapt for space use technology from terrestrial situations. And, in yet other cases, systems and devices from the commercial or the defense arenas can be taken and used directly.

In any event, the Space Station Program can provide a highly visible focus for advances in automation and robotics and be a stimulator or "driver" for the needed advances.

Remote operations (teleoperations) can be conducted under human control with the human operator feeling present at the worksite (telepresence).



These advances could have benefits not only for space activities but also for U.S. technology in general.

For space activities, the benefits could be

- Increased productivity—with astronauts functioning as managers on behalf of station users rather than as operators carrying out routine functions
- Increased responsiveness to innovation—with the automated Space Station being more flexible and adaptable
- Lower cost of operations—with highly automated systems that can run at peak efficiency
- Improved reliability—with machine intelligence contributing to improved detection, diagnosis, repair, and recovery from abnormal situations
- Greater autonomy—with machine intelligence to support monitoring and control of station systems, thereby lessening reliance on ground support
- The ability to perform with robots and teleoperators tasks unsuited to humans alone—such as the assembly of large structures
- A reduced need, because of the use of robots and teleoperators, to expose humans to hazardous situations—such as extravehicular activities, fueling tasks, and servicing satellites in high orbits (where radiation could be harmful)

For the U.S. economy, the benefits will be

- A Space Station more suitable for commercial ventures with flexible and reliable systems and crew time for management actions
- The application of advances in automation and robotics stimulated by space ventures to terrestrial situations in settings ranging from the factory floor to the homebound elderly and on to the bottom of the sea

Manipulating devices can be improved for many applications.
(Courtesy of Oceaneering International, Inc.)

Devices to help the handicapped will come from advanced automation and robotics.

Recommendations to NASA for Advancing Automation and Robotics Technology

Because automation and robotics are so important, all Space Station Program elements (the "core" station, orbiting platforms, orbital maneuvering vehicles, and ground facilities) will make substantial use of these technologies as part of the basic program. However, much greater use could be made if research and development were accelerated in an augmented program. The Advanced Technology Advisory Committee has not evaluated the funding required to develop the technology base for such an augmented program. However, the Automation and Robotics Panel has addressed this matter and recommends a strong applications research program. The panel's desired level of additional funding is 13 percent of total Space Station costs; the minimum acceptable level for such a program is 7 percent. Additional funds would be needed for the adaptive engineering necessary to prepare the new technology for Space Station use. Such an augmented program would incorporate automation and robotics technology at a much faster pace than would the basic program. And the augmented program would result in somewhat greater productivity from the initial station, and much greater productivity from later versions of the station.

Recommendations for the Basic Program

To implement automation and robotics (A & R) in the basic Space Station Program, the Advanced Technology Advisory Committee makes the following recommendations:

1. Automation and robotics should be a significant element of the Space Station Program.

The Space Station should be used as a medium for promoting automation and robotics within the nation.

Automation and robotics should be made a program-wide concern, equal in importance to safety or reliability.

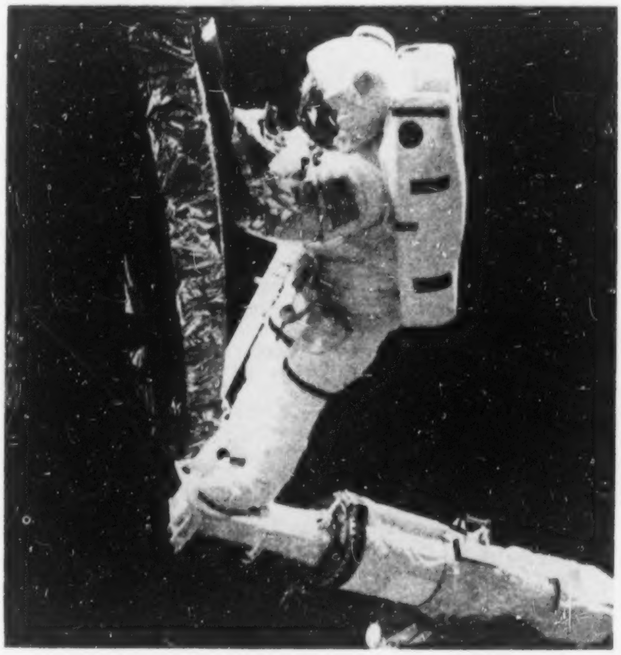
Research and development work should be focused specifically on automation and robotics.

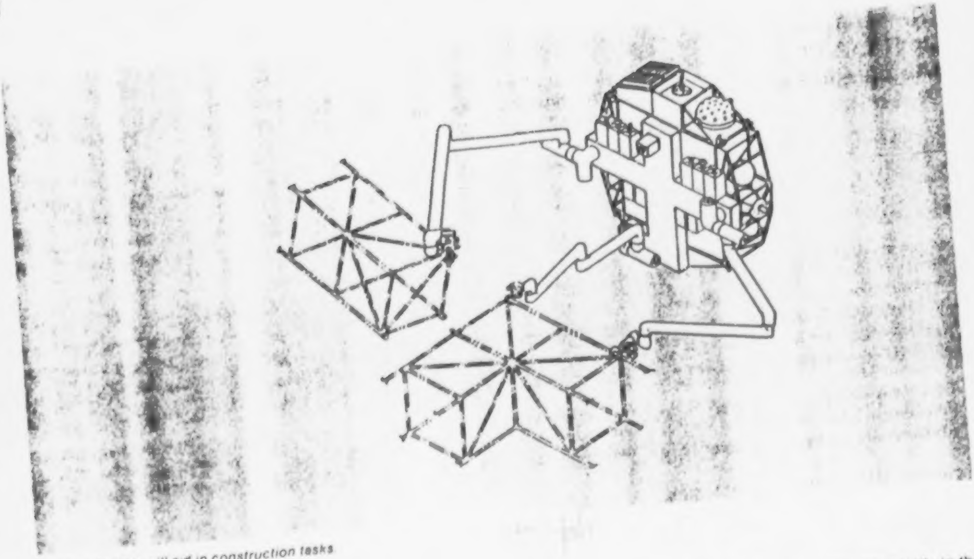
2. The initial Space Station should be designed to accommodate evolution and growth in automation and robotics.

Space Station system architecture should be developed to accommodate evolving A & R technology by:

- Designing the Space Station data system to be supportive of artificial intelligence and robotics technologies and reserving the necessary capacity.
- Capturing in the data base the Space Station design, including computer-aided representations and the *whys* or rationale thereof, to support later operations of expert systems (i.e., systems that simulate the behavior of human experts in certain specialized areas).

Initial station assembly will require astronauts aided by manipulators.





Robotic devices will aid in construction tasks.

- Maintaining, in the design process, the flexibility to incorporate new hardware as late as possible
- Using standard (yet evolvable) hardware, especially fittings and connectors, and standard marking techniques, such as bar codes
- Using standard programing languages
- Incorporating machine intelligence in the form of expert systems, first in well-defined and structured situations and later in more difficult situations
- Providing numerous sensors throughout the Space Station so that all elements can monitor their own well-being
- Providing ready access to the data base by station control systems, crew, and ground support staff under all station-operating and test conditions
- Designing the station to facilitate robot mobility, both within the station (intravehicular) and outside the station (extravehicular)
- Designing the station for eventual autonomy, with control by intelligent onboard devices and backup from intelligent ground-based systems, with human control as a last resort

Selection of contractors for detailed design and construction (phases C and D) should be influenced by the awareness of A & R issues displayed by the contractor during earlier work.

3. The initial Space Station should utilize significant elements of automation and robotics technology.

Applications of the A & R technology available at the time of the preliminary design review should be considered for the initial station. The initial station will include sufficient emphasis on automation and robotics to promote the accommodation of future developments, especially in the area of general-purpose systems and devices.

NASA should conduct a set of progressive, experimental demonstrations/evaluations to determine what A & R technology can be incorporated into the initial station. Possible demonstrations are

- An intravehicular, voice-controlled inspection robot
- A mobile "go-fer" robot to assist in crew tasks
- A control device that uses artificial intelligence to enhance traditional automatic control

Specific goals are addressed in the next section.

Essential to the success of the demonstrations is that testing be done under realistic conditions. This requires that evaluations be conducted with the test item "embedded," that is, functioning in an environment that resembles the eventual operational environment.

Because the Space Station crew would interact at every turn with the A & R elements, many of which have safety implications, the astronaut corps should be represented from the beginning and the design approach should incorporate manual means to override automatic systems. This way crew confidence in automated systems and robotic devices would be developed and safety would be assured.

4. Criteria for the incorporation of A & R technology should be developed and promulgated.

Criteria for Space Station use of the new technologies should focus on measurable issues such as productivity and annual operating costs and on potential benefits such as the merits of transferring space A & R technology back to terrestrial applications. Each application should be carefully selected and implemented according to these criteria to minimize overall system risks and costs and to improve system reliability.

5. Verification of the performance of automated equipment should be stressed, including terrestrial and space demonstrations to validate technology for Space Station use.

Many aspects of A & R technology are not yet well understood. Thus, applications would require careful verification before being used in life-critical systems. Furthermore, any implementation must recognize that, when subsystems interact with one another, the A & R aspects of those subsystems can lead to even more complex interactions.

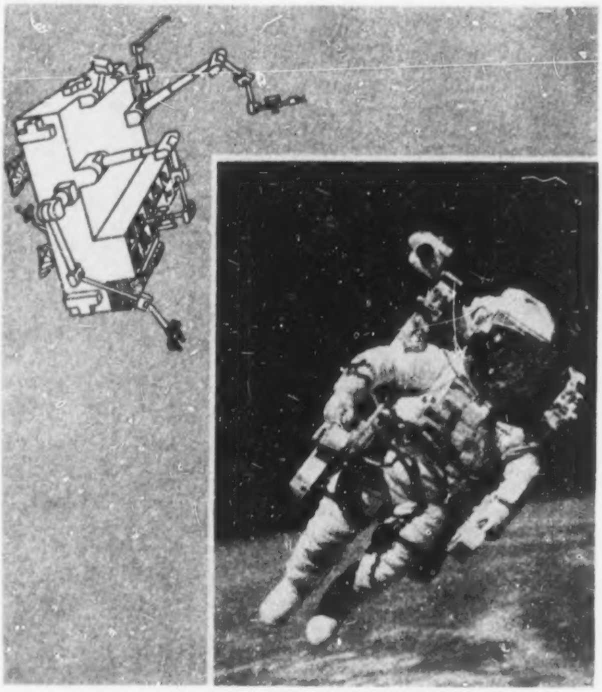
6. Maximum use should be made of technology developed for industry and Government.

Extensive work in automation and robotics is currently underway in industry, academia, and Government agencies. Current and future technology from these activities should be considered and used in the Space Station, provided the technology is applicable and has been qualified for space use. Examples might be

- Robots designed for terrestrial applications, modified as necessary for space applications in microgravity
- Products from the Strategic Computing Program of the Defense Advanced Research Projects Agency

A commercial approach to A & R hardware and software should be taken, as contrasted to a Department of Defense approach. However, NASA would remain cognizant of technology developed by the Department of Defense.

An "apprentice" astronaut can assist in many tasks.



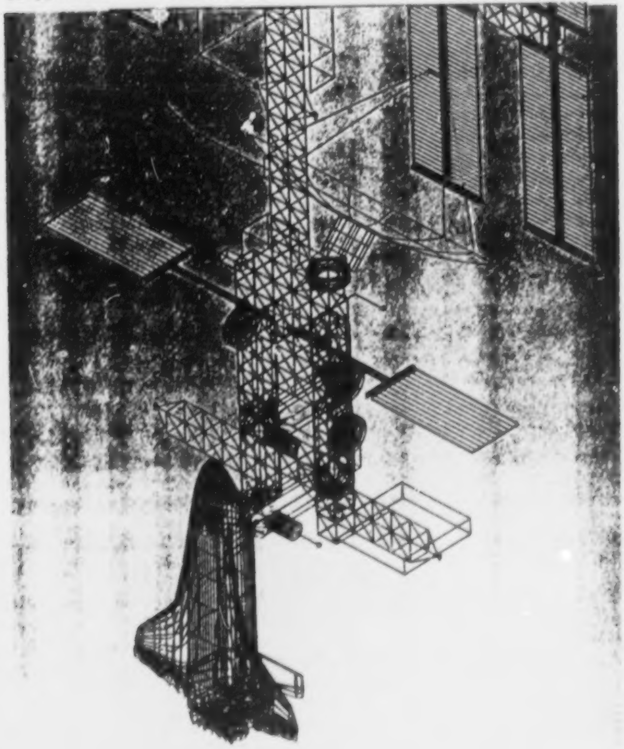
7. The techniques of automation should be used to enhance NASA's management capability.

A major effort will be made to use automation technology in the management process itself. For example, a technical management information system is being developed to link all participating organizations. This will employ the most current office automation and computer-aided design, manufacturing, and engineering (CAD/CAM/CAE) techniques.

8. NASA should provide the measures and assessments to verify the inclusion of automation and robotics in the Space Station.

Quantitative goals should be established for various Space Station A & R technologies and appropriate measures defined to assess progress.

Computer-aided design is vital to the Space Station.



Recommendations for an Augmented Program

If research and development can be accelerated in an augmented program, then a great deal more automation and robotics technology can be incorporated into the Space Station. Not only will the initial station be able to make greater use of such systems, but the evolutionary versions of the station will be much more highly automated and approach autonomous operation.

Given such an augmented program, the Advanced Technology Advisory Committee would make the following recommendations.

9. The initial Space Station should utilize as much automation and robotics technology as time and resources permit.

Further research and an acceleration of development and testing would give much greater insight into what can be expected for later versions of the station. Thus, more complete provision could be made for accommodating such developments. Additional, important demonstrations would be conducted; notably, an extravehicular robot capable of replacing failed parts on orbit.

Also, early demonstrations of A & R applications, including flight experiments, would be planned and carried out before the end of phase B.

10. An evolutionary station should achieve, in stages, a very high level of advanced automation.

The Space Station will be evolutionary in nature; it should be developed in such a way as to allow facile introduction of future A & R technology advances.

Each Space Station function, element (such as a platform), and subsystem should be considered for A & R technology application.

At the levels of automation anticipated for an evolutionary station, autonomous operation would be the norm.

A primary thrust would be to minimize ground and crew involvement in fault isolation, redundancy management, and routine servicing of onboard systems and payloads.

The interaction between crew and system—the human/machine interface—should be as natural as possible; for example, voice control of an "apprentice" by a crewmember.

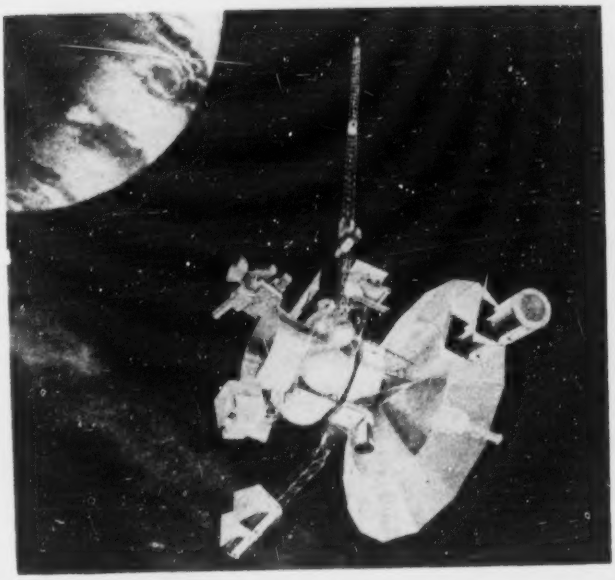
11. An aggressive program of long-range technology advancement should be pursued, recognizing areas in which NASA must lead, provide leverage for, or exploit developments.

NASA should try not only to promote advancements that are currently foreseen but also to stimulate improve systems and devices radically. Flexible, general-purpose systems are particularly important. Such systems could perform in situations not pre-planned by their designers and thus provide the adaptable and intelligent capabilities suitable for a space infrastructure that will serve a variety of needs.

NASA should solicit the involvement of entrepreneurs, especially those in small businesses, in Space Station automation and robotics for innovative ideas.

12. A vigorous program of technology transfer to U.S. industries and research and development communities should be pursued.

A Space Station Program pursued with an augmented effort to research and develop automation and robotics would be much more visible and attractive to potential terrestrial users of the technology. And there would be vastly more technology to transfer.

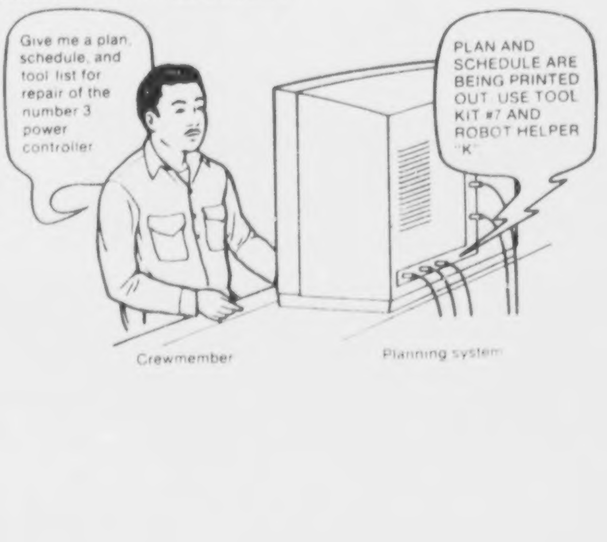


Future planetary spacecraft will be highly autonomous.

Major emphasis should be given to transferring the A & R technologies from the Space Station to private sector organizations contemplating commercial space activities.

Potential international participants in the Space Station Program must be sensitive to U.S. concerns about technology transfer that results in exporting jobs. NASA should use appropriate regulations to protect the A & R technology it uses and develops.

A voice communication is natural and efficient.


Give me a plan, schedule, and tool list for repair of the number 3 power controller.
PLAN AND SCHEDULE ARE BEING PRINTED OUT. USE TOOL KIT #7 AND ROBOT HELPER "K".
Crewmember
Planning system

13. Satellites and their payloads accessible from the Space Station should be designed, as far as possible, to be serviced and repaired by robots.

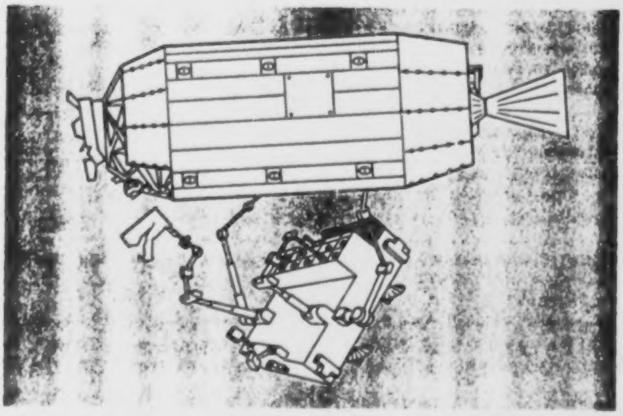
Management Approach and Schedule

NASA is concerned also with having an adequate mechanism to ensure that the intent of Congress is met and that A & R technology is appropriately used and advanced.

NASA should use the Space Station "definition and preliminary design" process (phase B) to define the automation and robotics to be used in the initial Space Station and to indicate the advances that will be needed as the Space Station evolves. An implementation plan using a systems approach and progressive, experimental demonstrations/evaluations is being prepared by the Office of Space Station. This approach will ensure that guidance from Space Station Program managers at all levels and innovative thinking from phase B contractors will be brought to bear on the evolution of automation and robotics.

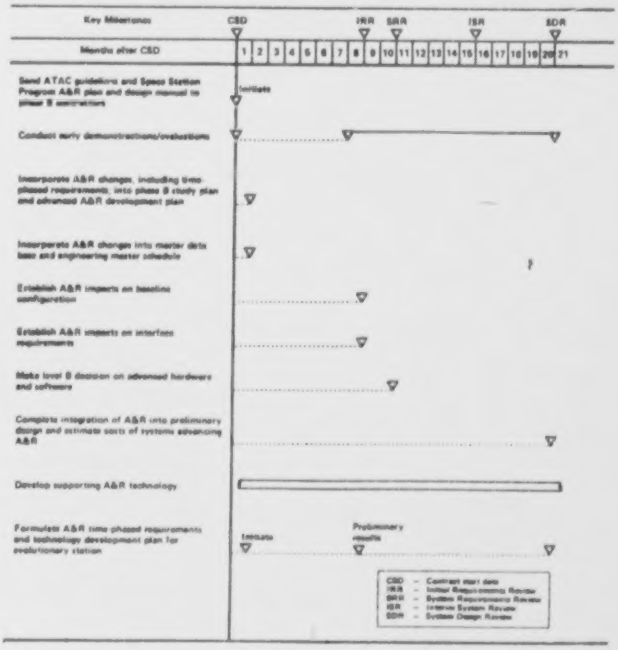
The Advanced Technology Advisory Committee is in agreement with concerns expressed by the Automation and Robotics Panel that Space Station Program managers have a formidable job without having to be responsible for long term A & R development. NASA should supply a management focus that will provide the necessary visibility and thrust to this task. The Advanced Technology Advisory Committee will continue to follow A & R needs and report to Congress semi-annually.

A proposed schedule for phase B activities in automation and robotics is given in table 1.



In the future robots will service satellites.

TABLE 1.— PROPOSED AUTOMATION AND ROBOTICS MILESTONES DURING SPACE STATION DEFINITION AND PRELIMINARY DESIGN



Goals for Advanced Automation and Robotics Applications

Automation would enhance all elements of the Space Station Program — the core station, orbiting platforms, orbital maneuvering vehicles, and ground facilities. There should be an evolutionary progression toward realizing an autonomous space station. However, all initial designs should utilize as much mature automation as technologically feasible while not precluding eventual growth. Subsystem design should be targeted conceptually for a mature (year 2010) space station, and modifications should be made as necessary for the initial station, recognizing the readiness of the technology and the lead time required to achieve implementation.

The Advanced Technology Advisory Committee has distilled the results of its study, the findings of the Automation and Robotics Panel, and the results of contractor and SRI studies into a set of goals that should be pursued. Table 2 depicts proposed goals (by no means an exhaustive list) for advanced automation and robotics on the initial station.

Further, the committee believes that it is beneficial to suggest a path along which the evolution of automation and robotics could proceed. Thus, while we recognize that projections into a time as distant as a mature station (year 2010) are hazardous, we present a set of proposed goals, table 3, as an indication of our current thinking.

TABLE 2.— PROPOSED GOALS FOR AUTOMATION AND ROBOTICS APPLICATIONS, INITIAL SPACE STATION

- **Electrical Power**

  Controllers enhanced by expert systems for
  — Load distribution and switching
  — Solar array orientation
  — Trend analysis
  — Fault diagnosis

- **Guidance, Navigation, and Control**

  Expert systems for
  — Station attitude control
  — Experiment pointing
  — Orbital maintenance and reboost
  — Rendezvous navigation
  — Fault diagnosis

- **Communication and Tracking**

  An executive enhanced by expert systems for
  — Communication scheduling
  — Rendezvous tracking
  — Data rate selection
  — Antenna pointing

- **Information and Data Management**

  An executive enhanced by expert systems for control of
  — Subsystem statusing
  — Trend analysis
  — Fault diagnosis
  — Redundancy and configuration management
  — Data base management

- **Environmental Control and Life Support**

  Controllers enhanced by expert systems for
  — Trend analysis
  — Fault diagnosis
  — Crew alarm
  — Station atmosphere monitoring and control
  — Hyperbaric chamber

- **General**

  Teleoperation of mobile remote manipulator with collision avoidance

  Mobile multiple-arm robot with dextrous manipulators to inspect and exchange orbital replacable units

  Systems designed to be serviced, maintained, and repaired by robots

  Primary station control in space with appropriate backup

TABLE 3.— PROPOSED GOALS FOR ADVANCED AUTOMATION AND ROBOTICS APPLICATIONS, EVOLUTIONARY SPACE STATION

- **Propulsion**

  An intelligent controller for
  - Fuel distribution and management
  - Leak detection and evaluation

- **Electrical Power**

  An autonomous intelligent controller for
  - Power management
  - Fault detection and isolation
  - Maintenance scheduling

- **Guidance, Navigation, and Control**

  An intelligent controller for
  - Fully automatic rendezvous and docking
  - Space traffic control
  - Remotely piloted vehicles
  - Collision avoidance

- **Communication and Tracking**

  An intelligent system for
  - Automatic planning
  - Tracking multiple vehicles
  - Scheduling bulk data storage for communications blackouts
  - Detection, identification, and characterization of general targets

- **Information and Data Management**

  A intelligent system for
  - Fault detection, isolation, and repair
  - Natural language interface with crew

  A data base manager for
  - CAD/CAE bulk data storage facility
  - Retrieval and routing to requestors

- **Environmental Control and Life Support**

  An intelligent controller for
  - Ensuring fail-safe/fail-operational modes
  - Fault detection and isolation
  - Chemical analysis of air and water
  - Toxic gas analysis

- **Habitability**

  An intelligent system for
  - Health maintenance
  - Speech interpretation and synthesis
  - Physiological monitoring
  - Automated medical decisions
  - Trend analysis

- **Structures and Mechanisms**

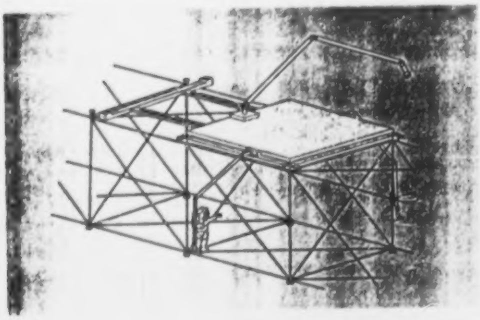
  Advanced work station
  Intelligent actuators
  Teleoperators

- **Orbiting Platforms**

  An intelligent system for
  - Process control
  - Maintenance control
  - Planning and trend analysis

- **General**

  Robots for
  - Inspection, maintenance, refurbishment, and repair
  - Fuel and materials transfer
  - Detecting hazardous leaks
  - Satellite retrieval and servicing



Major construction tasks will be aided by robots.

Case Studies of Automation and Robotics Issues

A number of case studies of advanced automation and robotics have been conducted recently by U.S. aerospace companies. These studies have provided very helpful insights into a number of representative situations. The companies and topics studied are

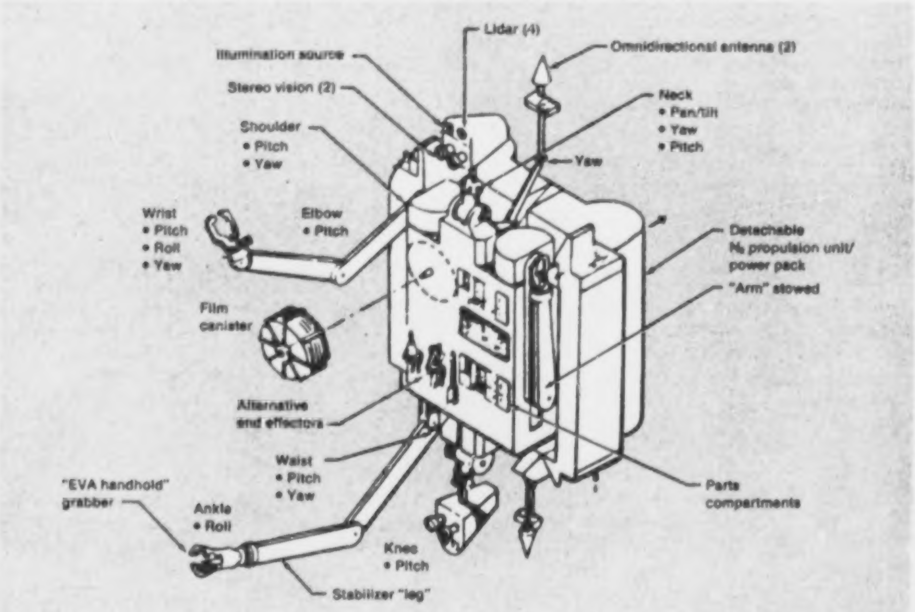
- Boeing
  - Operator/System Interface
- General Electric
  - Space Manufacturing Concepts
- Hughes
  - Subsystem and Mission Ground Support
- Martin-Marietta
  - Autonomous Systems and Assembly
- TRW
  - Satellite Servicing

The salient findings of each of these studies are summarized in the following paragraphs.

Operator/System Interface

Boeing studied the automation and robotics issues connected with the operator/system interface (OSI), sometimes called the human/machine interface, of the Space Station. This study, which was contributed by Boeing, drew upon a multimillion-dollar technology assessment carried out earlier by Boeing which produced a model of the technology advances that could be expected for various investments.

The study focused on the functional requirements for the operator/system interface and the A & R technologies needed to meet these requirements. The specific topic was the interface for an extravehicular (EV) robot of the type which would move about the Space Station and perform physical tasks at various worksites. The operator/system interface for this robot would perform path planning, tracking and control, object recognition, fault detection and correction, and plan modification.


Free-flying robots can perform many extravehicular tasks, such as retrieving film from a photographic platform.
Lidar (4)
Omnidirectional antenna (2)
Illumination source
Stereo vision (2)
Neck
• Pan/tilt
• Yaw
• Pitch
Shoulder
• Pitch
• Yaw
Yaw
Wrist
• Pitch
• Roll
• Yaw
Elbow
• Pitch
Detachable
N₂ propulsion unit/
power pack
"Arm" stowed
Film
canister
Alternative
end effectors
Waist
• Pitch
• Yaw
"EVA handhold"
grabber
Ankle
• Roll
Parts
compartments
Knee
• Pitch
Stabilizer "leg"

The major conclusions are these:

- It is technically feasible to develop an initial, fairly rudimentary EV robot and operator/system interface by the mid-1990s and a sophisticated, efficient, and convenient system by about 2010. The initial operator/system interface would have a limited supervisory capability and would be largely experimental in nature.
- An EV robot has great potential for relieving astronauts of routine and hazardous tasks and for increasing the level of extravehicular activity in support of the Space Station.

The following artificial intelligence technologies need to be emphasized in order to develop OSI capabilities:

Language representation
Natural language understanding
Analogical reasoning
Nonmonotonic reasoning

Boeing recommended a program to develop the EV robot operator/system interface and described how such a program could be undertaken.

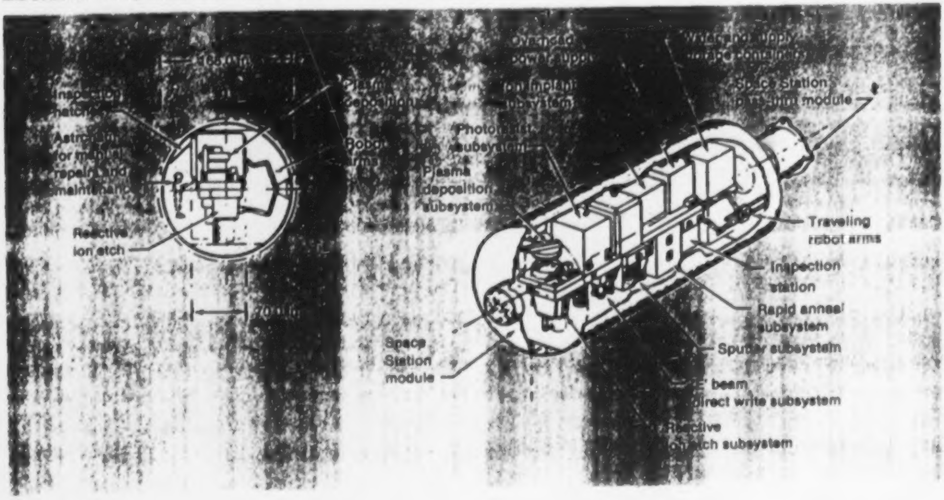
Space Manufacturing Concepts

General Electric developed conceptual designs for two space manufacturing facilities to define factory automation requirements. The facilities studied were for the production of gallium arsenide (GaAs) crystals and for the processing of microelectronic chips from such GaAs material.

The major conclusions are these:

- The manufacturing concepts studied are representative of innovative, technologically advanced systems.
- The major challenge is how to maintain, repair, and refurbish the production equipment.
- Space manufacturing automation requirements and design approaches can be defined for process mechanization, teleoperation and robotics, sensors, and artificial intelligence.
- Teleoperators and robots can be based on present designs, but space versions will be very different. They must be lightweight, and they will have different kinematics and dynamics in the microgravity environment.
- Artificial intelligence and expert systems must evolve as each facility is developed.
- "Intelligent" tools needed for repairs, modifications, and fabrication of equipment in space will generally use teleoperation incorporating a high degree of telepresence.

Microelectronic components can be made in an efficient space factory.


Inspection hatch
Astronaut for manual repair and maintenance
Reactive ion etch
Plasma deposition
Robot arms
Overhead power supply
Ion implant subsystem
Photoresist subsystem
Plasma deposition subsystem
Space Station platform module
Traveling robot arms
Inspection station
Rapid anneal subsystem
Sputter subsystem
E beam direct write subsystem
Reactive ion etch subsystem
Space Station module

- Many routine functions, such as removal or installation of standard retainers and replacement of expendables, will eventually utilize intelligent robots.

- Experiments in space must be conducted to prove A & R designs and capabilities.

General Electric recommended five near term A & R studies and experiments.

Subsystem and Mission Ground Support

Hughes studied the issues of automation in the areas of subsystem control and mission operations. The thrust was to develop concepts for autonomous operation and to assess the benefits and technology requirements of such concepts.

The study addressed electrical power, thermal control, and communications operations as representative subsystems, with emphasis on communications. The concept required automated capability to detect, isolate, and recover from failures.

Hughes recommends the following:

- Automatic speech recognition and synthesis should be considered a basic mode of human/machine interaction for Space Station command and control.

- The data management system and other subsystems of the Space Station should be designed to accommodate fully automated fault detection, isolation, and recovery.

Autonomous Systems and Assembly

Martin-Marietta asked what is the highest level of automation that could conceivably be accomplished by the year 2000 and what automation technology for assembly, construction, repair, and modification could be applied to the Space Station.

Martin-Marietta's major recommendations are as follows:

- Automation capability will grow rapidly and the Space Station needs to be flexible in design in order to accommodate this evolution.

- A cost-effective approach is to build in provisions for future modifications, for example, access corridors, berthing ports, and worksite "rest points" on which manipulating devices can be positioned.

- Status and warning capabilities for subsystems and for the total station should be provided.

- Human involvement in construction will start at an intensive level but decrease slowly until humans provide only a contingency capability.

Emphasis needs to be placed on the following technologies to support Space Station development:

- Teleoperation
- Proximity, touch, and force sensors
- Predictive displays
- Low-weight dextrous arm
- Dual-arm coordination
- Advanced activators
- Knowledge-based systems
- Planners, strategic and tactical
- Expert systems
- Machine vision
- Special and multifinger end effectors

Satellite Servicing

TRW addressed the issues of automated satellite servicing from the Space Station to determine benefits, methods, and best combinations of human/machine activities and to project needed technology advances.

The study considered four representative mission scenarios; i.e., low Earth orbit satellites, a co-orbiting materials-processing facility, payloads attached to the Space Station, and a geostationary satellite serviced by a recoverable orbital transfer vehicle (OTV).

The major conclusions are these:

- Automation can make satellite servicing more productive, but accelerated development of automation hardware is needed.

- Servicing poses automation requirements significantly different from those of other Space Station orbital activities.

- Telepresence is the principal automation discipline required for servicing, with human operator involvement to handle task diversity and unforeseen situations.

- Geosynchronous satellite servicing demands more reliance on the full robotic mode, with human supervisory control and teleoperation preferably performed from a ground station rather than from the Space Station.

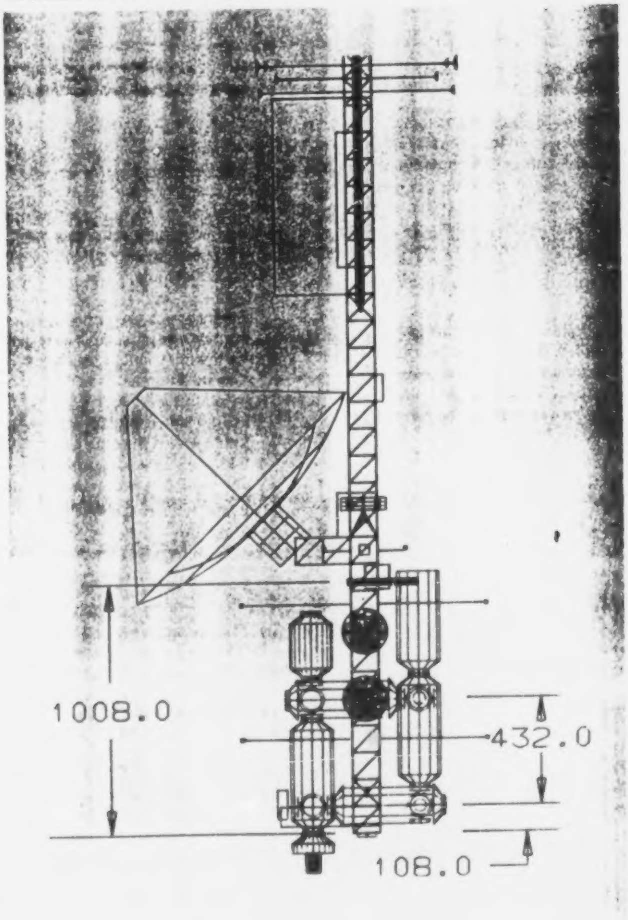
- Massive data system and artificial intelligence support is needed in planning, sequencing, and executing tasks.

- Major benefits to terrestrial applications will be in the area of flexible/adaptable automation.

TRW's recommendations for advancement of automation and robotics technology include emphasis on

- Robotic vision
- Standardized interfaces designed for automated servicing
- Intelligent servicing kits (e.g., for the OTV)
- Pressurized, movable work stations

An onboard data base can retain graphic details on the station design.



Benefits for the U.S. Economy

"The conferees both intend and expect that the technologies of Space Station automation and robotics will be identified and developed not only to increase the efficiency of the station itself but also to enhance the Nation's technical and scientific base leading to more productive industries here on Earth." So states report 98-867 of the Committee of Conference, a report that accompanies bill HR 5713, which authorizes funding for the Space Station.

The strength of the U.S. economy is closely linked to advances in technology. Keeping the economy robust requires a continuing injection of new technology of the type that can be developed in the Space Station Program. Indeed, we believe that the economy needs the same flexible, general-purpose machine intelligence and robotics, thus the benefits expected by Congress can be realized if the technology advances described in this report are made successfully and then adapted to industries on Earth.

Contrary to popular fears, the application of A & R technology is not expected to decrease the number of jobs in the U.S. economy but may actually increase that number. Evidence from several studies, including studies by a congressional subcommittee and the Office of Technology Assessment, support this assertion. One summary statement concluded that, "in the long run, industrial robots should lead to improved working conditions, higher real wages and the creation of more jobs."

Technology Transfer

There are many possible applications of advanced automation and robotics to the terrestrial economy. Two of these are typical.

Expert Systems
Already beginning to come into use in the marketplace, expert systems model the performance of the best human experts in certain specialized areas. Notable success has been achieved in such tasks as determining what combination of components will make up the best computer system for a particular job, diagnosing problems in locomotives and suggesting repair procedures, and providing assistance in medical diagnoses.

Such systems figure prominently in the A & R advances that the Space Station could bring about. As indicated in tables 2 and 3, a large array of control and troubleshooting functions could be handled or enhanced by expert systems. Since many of these functions are equally important in terrestrial situations, the transfer of the technology should be very direct.

The transfer of advanced expert systems back to the terrestrial economy could, by the year 2000, result in major productivity improvements not only in industry but also in health care, transportation, communications, and many other sectors of the economy.

Adaptive Control for Robots
Critical needs exist in industry today for certain types of automation technology. For example, adaptive control for robots is needed to accomplish automated assembly tasks. Factors such as the requirement for autonomy, safety constraints, and productivity considerations will drive the development of adaptive control technology. The means exist within NASA to transfer such technology, if developed for the Space Station, to U.S. industry.

If adaptive control technology were available to large and small industries alike, the impact could be considerable. One preliminary estimate (Digeronimo) is that if NASA were to begin a vigorous development effort in automation and robotics in 1985 and continue through

Expert systems for diagnoses will aid greatly in health care.

2000, the annual sales of industrial robots for assembly applications alone would increase by $600 million over currently projected sales.

There are many possible applications of intelligent robots. Some of these are depicted in table 4.

TABLE 4.— POTENTIAL INTELLIGENT ROBOT APPLICATIONS IN THE U.S. ECONOMY

Settings	**Uses**
Factories (manufacturing, light industry)	Welding, machining, painting, molding, assembly, inspection, repair, loading, packaging
Offices and institutions (hospitals, schools, prisons)	Distribution (mail, supplies, food), cleaning (floors, windows, trash)
Undersea	Surveying, search and rescue, cable laying, construction, extraction
Mining; oil and gas	Extracting, drilling, rescue (firefighting, boring), processing
Nuclear power plants	Maintenance, emergency operations
Agriculture	Harvesting, planting, irrigation, fertilizing, weed and pest control
Construction	Excavations, structure erection and demolition
Home	Aiding elderly or handicapped

Commercialization of Space

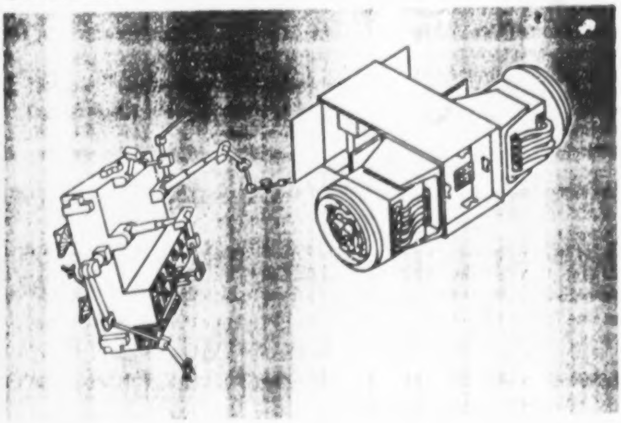
Benefits will also accrue to the U.S. economy because of commercial activity in space. Some observers, in fact, see space as the next big industrial frontier. Commercial activity in space will result in the production of unique goods for sale to consumers and industrial customers on Earth. Automation would make the Space Station more flexible and adaptable and less costly to operate. Thus, by making station facilities more productive, it would make the Space Station a better environment for commercial applications.

An example of the benefits of such space commercial activity has already been cited in the case study on space manufacture of gallium arsenide crystals and microelectronic chips from such material. Such manufacturing could lead to more efficient electronic devices for terrestrial use. Automation is a key element in the successful commercialization of space, as described by General Electric in their study.

The commercialization of space in the sense of commercial satellites, such as for communication, is well established. Advances in automation and robotics could enhance the capability to support such satellites with space assembly, maintenance, and repair.

Industrial processes can be improved using advanced automation and robotics.

The technology underlying intelligent robots developed for space use can be applied to terrestrial tasks.



Closing Remarks

NASA must meet the significant challenges posed by the competitive, commercial era of the U.S. space program in its second 25 years. An important factor in meeting these challenges successfully should be the creation, adaptation, and application of a large array of automation and robotics technology to diverse situations in the Space Station. Equally important, NASA should promote the transfer of the new technology to terrestrial situations where it will benefit the U.S. economy.

The timely, successful generation and application of automation and robotics technology could have profound effects. When the technology is widely dispersed throughout our society, as the NASA technology transfer process allows, Americans could have a significantly improved capability to handle complex tasks that require the codification and mechanization of knowledge. The new technology could improve the capability of our industrial and political leaders to utilize the nation's pool of knowledge and to manage large enterprises effectively, flexibly, and with greatly increased productivity.

Successful incorporation of automation and robotics by the Space Station Program could lead to the deployment of a new generation of flexible and adaptable space systems. These systems could provide the United States with important new methods of generating and exploiting space knowledge in commercial enterprises and thereby help preserve U.S. leadership in space.

Although there are difficult challenges to meet, ATAC believes that NASA can achieve the goals of a national program of such scope and complexity. A substantial return on invested resources in terms of increased Space Station productivity and increased economic strength can be expected.

Study Organization and Participation

In response to the mandate from Congress to address advanced automation and robotics, NASA undertook to enlist as much expertise as was reasonably available. A concerted effort was made to involve aerospace contractors, industry, and universities. The work was structured into three major elements, carried out by the Advanced Technology Advisory Committee, by the Automation and Robotics Panel, and by SRI International and aerospace contractors. The organizational methodology used for this Space Station automation study is depicted in figure A. The manager of the study is Dan Herman, NASA Headquarters, and the deputy manager is Victor Anselmo, NASA Headquarters. The chairman of the steering committee for the study is Robert A. Frosch, Vice-President, General Motors Corporation.

The Advanced Technology Advisory Committee was formed pursuant to PL 98-371. The members of the committee, listed in table I, were selected not only because of their professional experience and capability, but because the organizations they represent will be those responsible for assuring a high level of A & R accommodation in the initial Space Station and its associated platforms. The committee was tasked to consider the charge from Congress, the needs and limitations of the Space Station program, and the findings of the other studies and then to provide recommendations to NASA.

The California Space Institute (Cal Space) of the University of California formed the Automation and Robotics Panel (ARP), which included representatives of industry, academia, and Government (table II). The panel was to study available and prospective technology and to provide an independent set of recommendations to NASA.

The aerospace contractors involved studied automation and robotics in specific areas as follows:

Boeing	Operator/System Interface
General Electric	Space Manufacturing Concepts
Hughes	Subsystem and Mission Ground Support
Martin-Marietta	Autonomous Systems and Assembly
TRW	Satellite Servicing

Because of the limited time available, the contractors were directed to identify "drivers" for advanced automation. They were not asked to address all automation and robotics applications for an evolutionary Space Station but only those believed to be typical.

SRI International provided a technology assessment based on the contractor studies, their own knowledge of the technology, and their anticipation of technology readiness.

Figure A.— Methodology for the Space Station automation study

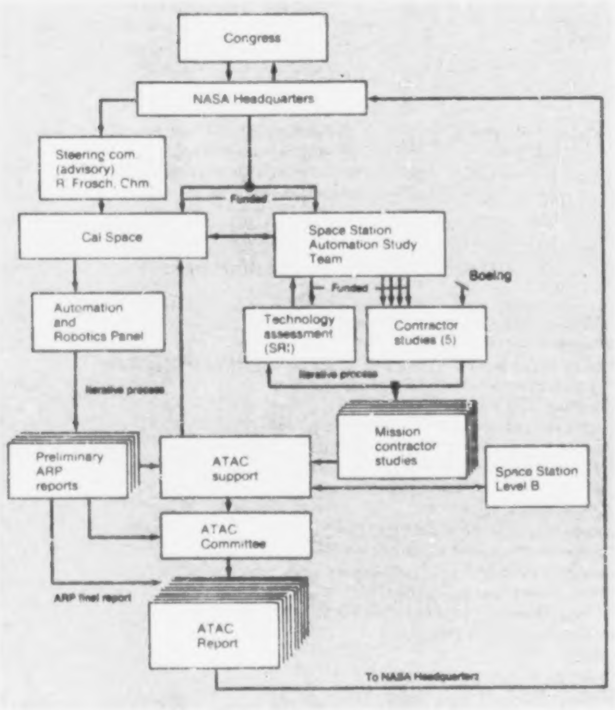

Congress
NASA Headquarters
Steering com.
(advisory)
R. Frosch, Chm.
Funded
Cal Space
Space Station
Automation Study
Team
Funded
Boeing
Automation
and
Robotics Panel
Technology
assessment
(SRI)
Contractor
studies (5)
Iterative process
Iterative process
Mission
contractor
studies
Preliminary
ARP
reports
ATAC
support
Space Station
Level B
ATAC
Committee
ARP final report
ATAC
Report
To NASA Headquarters

TABLE I.— SPACE STATION ADVANCED TECHNOLOGY ADVISORY COMMITTEE

Aaron Cohen, Chairman, Director of Research and Engineering, Lyndon B. Johnson Space Center (JSC)
John H. Boeckel, Director of Engineering, Goddard Space Flight Center (GSFC)
J. Larry Crawford, Assistant to the Chief Engineer, NASA Headquarters
Lynwood C. Dunseith, Assistant to the Director of Space Operations, JSC
J. Stuart Fordyce, Director of Aerospace Technology, Lewis Research Center (LeRC)
Paul F. Holloway, Deputy Director, Langley Research Center (LaRC)
James E. Kingsbury, Director of Science and Engineering, Marshall Space Flight Center (MSFC)
Allen J. Louviere, Manager, Space Station Level B Systems Engineering and Integration
Robert R. Nunamaker, Chief Engineer, Ames Research Center (ARC)
Donna L. Pivirotto, Manager, Space Station Office, Jet Propulsion Laboratory (JPL)

An ATAC support group (table III) was formed to assist in the effort. The members of the group functioned as a part of the Space Station automation study team, as observers at the ARP meetings, and as major participants in the support to ATAC. This support group assimilated the inputs from various contributors into this report.

The entire process of the Space Station automation study was an open and iterative one, with many information exchanges. All meetings, presentation documents, and so forth were open to all participants. This effort required and received extraordinary cooperation from the entire study team.

TABLE II — AUTOMATION AND ROBOTICS PANEL

James R. Arnold, California Space Institute (Cal Space)
Robert Cannon, Stanford University
Roger Cliff, Defense Advanced Research Projects Agency (DARPA)
Aaron Cohen, NASA/Johnson Space Center
Charles J. Cook, Bechtel Group, Inc
David R. Criswell, Cal Space
Doyle Evans, Los Alamos National Laboratory
Sidney Firstman, Georgia Institute of Technology
Harold Forsen, Bechtel National, Inc
Owen Garriott, NASA/JSC
David Groce, Science Applications, Inc. (SAI)
Robert M. Hambright, Southwest Research Institute
Hugh Hudson, University of California at San Diego
Demetrius G. Jelatis, Sargent Industries
Gene Konecci, University of Texas at Austin (UT Austin)
George Kozmetski, UT Austin
Michael Knasel, SAI
Peter B. Linhart, AT & T Bell Laboratories
Marvin Minsky, MIT & Thinking Machines, Inc.
Sanjay Mittal, Xerox Corp.—Palo Alto Research Center
John Niehoff, SAI
Roger Perkins, Los Alamos National Laboratory
Marc Raibert, Carnegie-Mellon University
Martin Reiss, United States Senate
Charles Rosen, Machine Intelligence, Inc.
Charles Ruoff, NASA/Jet Propulsion Lab
Jack Schwartz, New York University
Scott A. Starks, University of Texas at Arlington
Terry Triffet, University of Arizona
Richard Volz, University of Michigan
Bruce West, La Jolla Institute
Theodore J. Williams, Purdue University
Michael J. Wiskerchen, Stanford University

TABLE III.— ATAC SUPPORT GROUP

Jon D. Erickson, Chairman,
  Artificial Intelligence Office,
  Johnson Space Center
Victor Anselmo,
  Office of Space Station,
  NASA Headquarters
Jon B. Haussler,
  Space Station Office,
  Marshall Space Flight Center
Stephen J. Katzberg,
  Space Station Office,
  Langley Research Center
Louis E. Livingston,
  Space Station
  Program Office, JSC
Henry H. Lum,
  Information Sciences Office,
  Ames Research Center

Acknowledgments

This report was prepared for the NASA Advanced Technology Advisory Committee (ATAC) by the ATAC Support Group and members of the NASA Johnson Space Center Artificial Intelligence Office. The support group, the members of which are listed in table III, provided guidance on the purpose, contents, and organization, as well as making vital contributions to the draft material.

The JSC Artificial Intelligence Office provided the initial draft of the report and integrated comments and revisions to produce the final version. The contributors were

A. Glen Houston, Draft Leader
Kenneth R. Crouse
Jimmy R. Gilbert
Robert A. Goode
Michael F. Heidt
Richard P. Heydorn
Laurie Webster

Several individuals, representing various NASA organizations, provided vital assistance and draft material in preparing this document.

Ivan O. Clark, Langley Research Center (LaRC)
David E. Eckhardt, Jr., LaRC
Walter W. Hankins, LaRC
Daniel J. Jobson, LaRC
John A. Johnson, Jet Propulsion Lab (JPL)
Richard D. Kennedy, JSC
Herbert R. Kowitz, LaRC
Albert J. Meintel, LaRC
Barry D. Meredith, LaRC
Lanny J. Miller, JPL
L. Marion Pringle, Space Station Program Office
R. Rasmussen, JPL
David A. Rennels, JPL
Leigh S. Rosenburg, JPL
Robert L. Staehle, JPL
Kent Volkmer, JPL
Claire M. Wolfe, Ames Research Center
Wayne F. Zimmerman, JPL
Arthur I. Zygielbaum, JPL

The technical writing was done by R. Bryan Erb, consultant, and the technical editing was done by Mary Fae McKay of JSC.

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Advanced Technology Advisory Committee (ATAC)
Aaron Cohen, Chairman

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Houston, TX 77058

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Washington, D.C. 20546

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15. Supplementary Notes

16. Abstract

In response to Public Law 98-371, dated July 18, 1984, the NASA Advanced Technology Advisory Committee has studied automation and robotics for use in the Space Station and prepared this report to the House and Senate Committees on Appropriations. The report is divided into two volumes:

- The Executive Overview, Volume I (this document), presents the major findings of the study and recommends to NASA principles for advancing automation and robotics technologies for the benefit of the Space Station and of the U.S. economy in general
- The Technical Report, Volume II, provides background information on automation and robotics technologies and their potential

As a result of its study, the Advanced Technology Advisory Committee believes that a key element of technology for the Space Station is extensive use of advanced general-purpose automation and robotics. This could include many systems and devices (such as computer vision, expert systems, and dextrous manipulators) that have been made possible by recent advances in artificial intelligence, robotics, computer science, and microelectronics.

Successful incorporation of automation and robotics by the Space Station program could lead to the deployment of a new generation of flexible and adaptable space systems. These systems could provide the United States with important new methods of generating and exploiting space knowledge in commercial enterprises and thereby help preserve U.S. leadership in space.

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ADVANCING AUTOMATION AND ROBOTICS TECHNOLOGY FOR THE SPACE STATION AND FOR THE U. S. ECONOMY

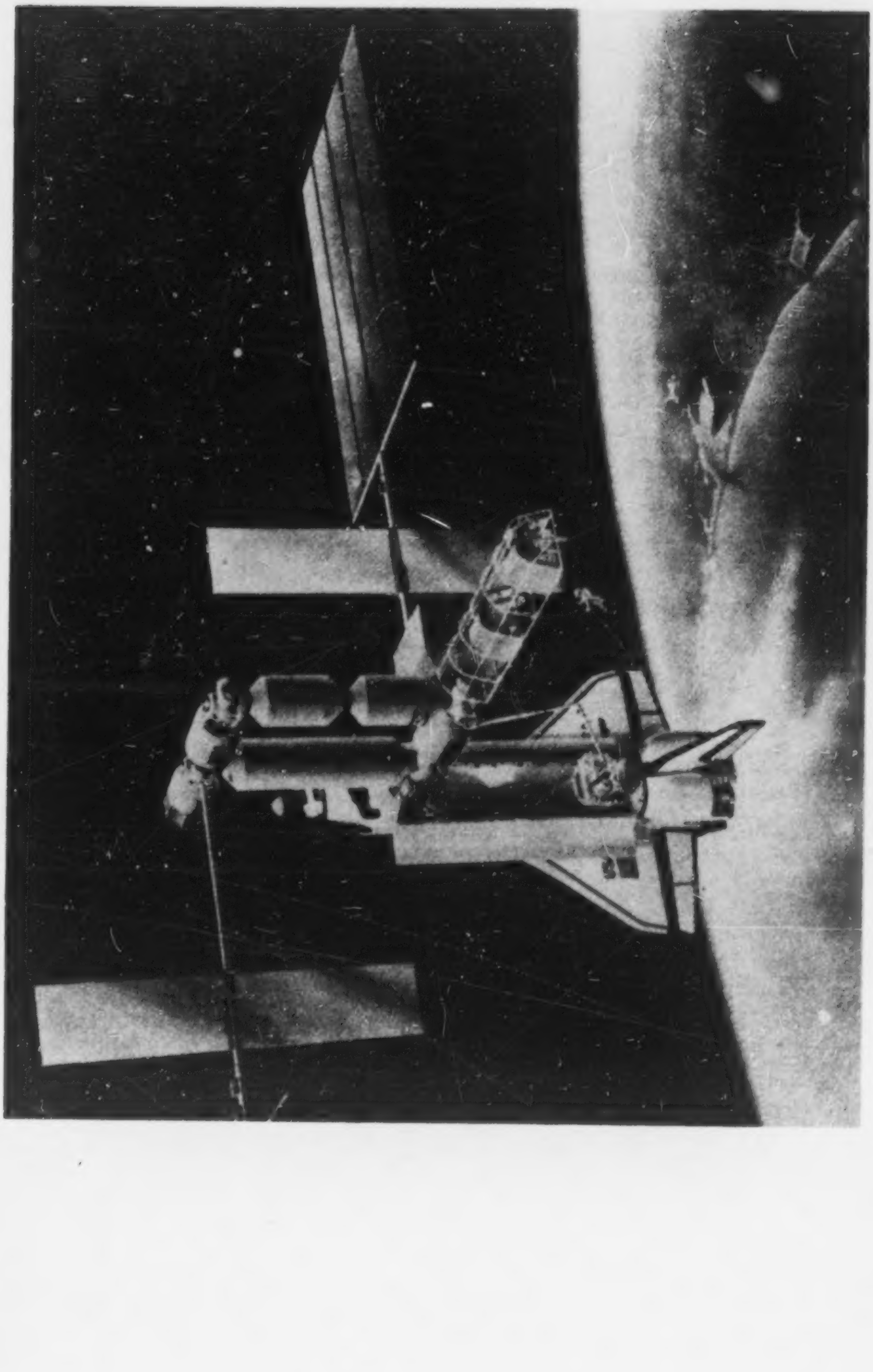
VOLUME II - TECHNICAL REPORT

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
ADVANCED TECHNOLOGY ADVISORY COMMITTEE

Submitted to the
United States Congress
March 1985

Prepared by

NASA Intercenter Working Group
and JSC Artificial Intelligence Office



PREFACE

In response to Public Law 98-371, dated July 18, 1984, the NASA Advanced Technology Advisory Committee has studied automation and robotics for use in the Space Station and prepared this report to the House and Senate Committees on Appropriations. The study has drawn on work by groups both within NASA and outside NASA, in the academic and industrial communities.

The report is divided into two volumes.

The Executive Overview, Volume I, presents the major findings of the study and recommends to NASA principles for advancing automation and robotics technologies for the benefit of the Space Station and of the U.S. economy in general.

The Technical Report, Volume II (this document), provides background information on automation and robotics technologies and their potential and documents the following:

- The relevant aspects of Space Station design
- Representative examples of automation and robotics applications
- The state of the technology and advances needed
- Considerations for technology transfer to U.S. industry and for space commercialization

Volume II provides guidance for prospective Space Station contractors to direct their efforts toward a planned advance in these technologies.

This report is referenced in the request for proposals for definition and preliminary design of the Space Station. Volume II in particular provides guidance for prospective Space Station contractors to direct their efforts toward a planned advance in these technologies.

In response to an agreement with the Senate Appropriations Committee in April 1984, NASA funded and managed a number of studies in the general area of automation and robotics. These studies were done by academic and industrial specialists working in the field, and they provided important insight to the Advanced Technology Advisory Committee.

An Automation and Robotics Panel, led by the California Space Institute, prepared the report "Automation and Robotics for the National Space Program." Five aerospace firms conducted studies of critical issues (discussed in chapter 5 of this volume). Further, SRI International studied the general state of the technology and areas in which research is needed. The documentation of all of these studies is referenced and should be read in conjunction with this report.

STUDY ORGANIZATION AND PARTICIPATION

In response to the mandate from Congress to address advanced automation and robotics, NASA undertook to enlist as much expertise as was reasonably available. A concerted effort was made to involve aerospace contractors, industry, and universities. The work was structured into three major elements, carried out by the Advanced Technology Advisory Committee, the Automation and Robotics Panel, and by SRI International and aerospace contractors. The organizational methodology used for this Space Station automation study is depicted in figure A. The manager of the study is Dan Herman, NASA Headquarters, and the deputy manager is Victor Anselmo, NASA Headquarters. The chairman of the steering committee for the study is Robert A. Frosch, Vice-President, General Motors Corporation.

The Advanced Technology Advisory Committee was formed pursuant to PL 98-371. The members of the committee, listed in table I, were selected not only because of their professional experience and capability, but because the organizations they represent would be those responsible for assuring a high level of accommodation of automation and robotics on the initial station and its associated platforms. The committee was tasked to consider the charge from Congress, the needs and limitations of the Space Station Program, and the findings of the other studies and also to provide recommendations to NASA.

The California Space Institute (Cal Space) of the University of California formed the Automation and Robotics Panel (ARP), which included representatives of industry, academia, and Government (table II). The panel was to study available and prospective technology and to provide an independent set of recommendations to NASA.

The aerospace contractors involved studied automation and robotics in specific areas as follows:

Boeing	Operator/System Interface
General Electric	Space Manufacturing Concepts
Hughes	Subsystem and Mission Ground Support
Martin Marietta	Autonomous Systems and Assembly
TRW	Satellite Servicing

Because of the limited time available, the contractors were directed to identify "drivers" for advanced automation. They were not asked to address all automation and robotics applications for the evolutionary Space Station but only those believed to be typical.

SRI International provided a technology assessment based on the contractor studies, their own knowledge of the technology, and their anticipation of technology readiness.

An ATAC Support Group (table III) was formed to assist in the effort. The members of the group functioned as a part of the Space Station Automation Study Team, as observers at the ARP meetings, and as major participants in the support to ATAC. This support group assimilated the inputs from various contributors into this report.

The entire process of the Space Station automation study was an iterative one, with many information exchanges. All meetings, presentation documents, and so forth were open to all participants. This effort required and received extraordinary cooperation from the entire study team.

TABLE I.- SPACE STATION ADVANCED TECHNOLOGY ADVISORY COMMITTEE

Aaron Cohen, Chairman, Director of Research and Engineering, Lyndon B. Johnson Space Center (JSC)
John H. Boeckel, Director of Engineering, Goddard Space Flight Center (GSFC)
J. Larry Crawford, Assistant to the Chief Engineer, NASA Headquarters
Lynwood C. Dunseith, Assistant to the Director of Space Operations, JSC
J. Stuart Fordyce, Director of Aerospace Technology, Lewis Research Center (LeRC)
Paul F. Holloway, Deputy Director, Langley Research Center (LaRC)
James E. Kingsbury, Director of Science and Engineering, Marshall Space Flight Center (MSFC)
Allen J. Louviere, Manager, Space Station Level B Systems Engineering and Integration, JSC
Robert R. Nunamaker, Chief Engineer, Ames Research Center (ARC)
Donna L. Pivirotto, Manager, Space Station Office, Jet Propulsion Laboratory (JPL)

TABLE II.- AUTOMATION AND ROBOTICS PANEL

James R. Arnold, California Space Institute (Cal Space)
Robert Cannon, Stanford University
Roger Cliff, Defense Advanced Research Projects Agency (DARPA)
Aaron Cohen, NASA/Johnson Space Center (JSC)
Charles J. Cook, Bechtel Group, Inc.
David R. Criswell, Cal Space
Doyle Evans, Los Alamos National Laboratory
Sidney Firstman, Georgia Institute of Technology
Harold Forsen, Bechtel National, Inc.
Owen Garriott, NASA/JSC
David Groce, Science Applications, Inc. (SAI)
Robert M. Hambright, Southwest Research Institute
Hugh Hudson, University of California at San Diego
Demetrius G. Jelatis, Sargent Industries
Michael Knasel, SAI
Gene Konecci, University of Texas at Austin (UT Austin)
George Kozmetski, UT Austin
Peter B. Linhart, AT&T Bell Laboratories
Marvin Minsky, MIT & Thinking Machines, Inc.
Sanjay Mittal, Xerox Corporation - Palo Alto Research Center
John Niehoff, SAI
Roger Perkins, Los Alamos National Laboratory
Marc Raibert, Carnegie-Mellon University
Martin Reiss, United States Senate
Charles Rosen, Machine Intelligence, Inc.
Charles Ruoff, NASA/Jet Propulsion Laboratory
Jack Schwartz, New York University
Scott A. Starks, University of Texas at Arlington
Terry Triffet, University of Arizona
Richard Volz, University of Michigan
Bruce West, La Jolla Institute
Theodore J. Williams, Purdue University
Michael J. Wiskerchen, Stanford University

TABLE III.- INTERCENTER WORKING GROUP

Jon D. Erickson, Chairman, Artificial Intelligence Office, Johnson Space Center
Victor Anselmo, Office of Space Station, NASA Headquarters
Jon B. Haussler, Space Station Office, Marshall Space Flight Center
Stephen J. Katzberg, Space Station Office, Langley Research Center
Louis E. Livingston, Space Station Program Office, JSC
Henry H. Lum, Information Sciences Office, Ames Research Center

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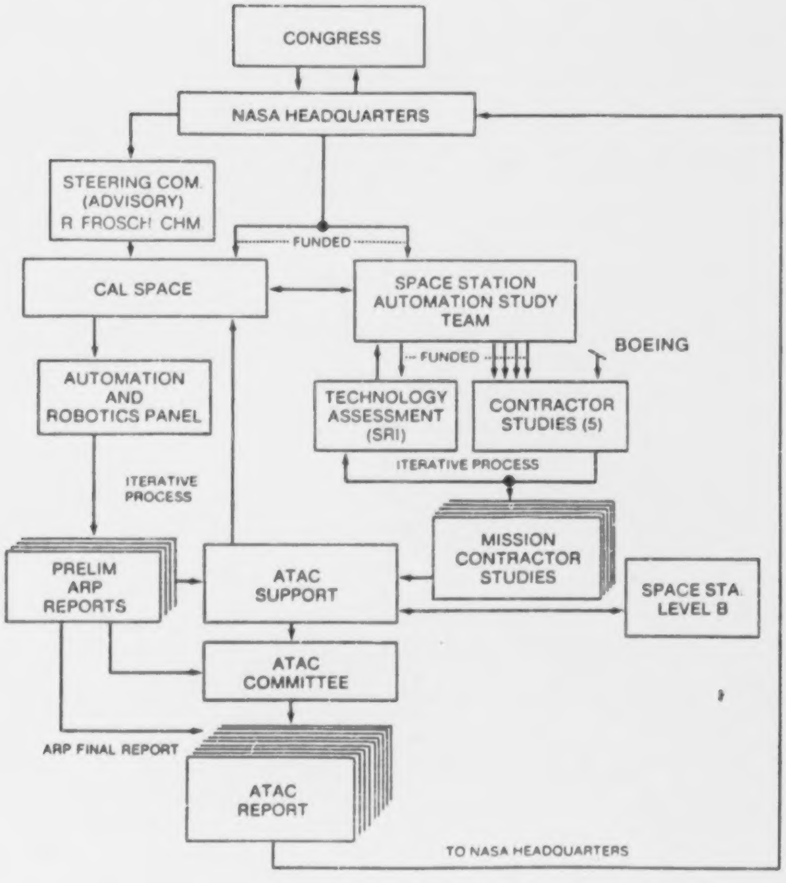
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CAL SPACE
SPACE STATION AUTOMATION STUDY TEAM
BOEING
FUNDED
AUTOMATION AND ROBOTICS PANEL
TECHNOLOGY ASSESSMENT (SRI)
CONTRACTOR STUDIES (5)
ITERATIVE PROCESS
ITERATIVE PROCESS
MISSION CONTRACTOR STUDIES
PRELIM ARP REPORTS
ATAC SUPPORT
SPACE STA. LEVEL B
ATAC COMMITTEE
ARP FINAL REPORT
ATAC REPORT
TO NASA HEADQUARTERS

Figure A.- Methodology for the Space Station automation study.

ACKNOWLEDGMENTS

This report was prepared for the NASA Advanced Technology Advisory Committee (ATAC) by the ATAC Support Group and members of the NASA Johnson Space Center Artificial Intelligence Office. The support group, the members of which are listed in table III, provided guidance on the purpose, contents, and organization, as well as making vital contributions to the draft material.

The JSC Artificial Intelligence Office provided the initial draft of the report and integrated comments and revisions to produce the final version. The contributors were

A. Glen Houston, Draft Leader
Kenneth R. Crouse
Jimmy R. Gilbert
Robert A. Goode
Michael F. Heidt
Richard P. Heydorn
Laurie Webster

Several individuals, representing various NASA organizations, provided vital assistance and draft material in preparing this document:

Ivan O. Clark, Langley Research Center (LaRC)
David E. Eckhardt, Jr., LaRC
Walter W. Hankins, LaRC
Daniel J. Jobson, LaRC
John A. Johnson, Jet Propulsion Lab (JPL)
Richard D. Kennedy, JSC
Herbert R. Kowitz, LaRC
Albert J. Meintel, LaRC
Barry D. Meredith, LaRC
Lanny J. Miller, JPL
L. Marion Pringle, Space Station Program Office
R. Rasmussen, JPL
David A. Rennels, JPL
Leigh S. Rosenburg, JPL
Robert L. Staehle, JPL
Kent Volkmer, JPL
Claire M. Wolfe, Ames Research Center
Wayne F. Zimmerman, JPL
Arther I. Zygielbaum, JPL

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Chapter 1

INTRODUCTION

"The wealth of nations, which depended upon land, labor, and capital during its agricultural and industrial phases - depended upon natural resources, the accumulation of money, and even upon weaponry - will come in the future to depend upon information, knowledge, and intelligence."

- Feigenbaum and McCorduck, 1984

We are at the beginning of a new era in space which poses significant new challenges as we move into the second 25 years of the U.S. space program. To meet the challenge of critical needs associated with achieving a permanent human presence in space and optimizing the commercial uses of space, the Advanced Technology Advisory Committee (ATAC) recommends that the National Aeronautics and Space Administration (NASA) emphasize an important element in its Space Station Program (SSP) called Automation and Robotics. By seizing an opportunity to leverage recent advances in artificial intelligence, robotics, computer science, and microelectronics, NASA can both use and advance a new generation of machine intelligence and robotics technology. This new technology promises to increase the productivity of humans in space, reduce operating costs, and increase U.S. economic strength over the coming decades. ATAC submits this report with cautious optimism.

CHALLENGES OF AUTOMATION AND ROBOTICS

There are a number of new challenges for the U.S. space program:

- We must make use of the new technologies becoming available to assure effective utilization of our resources.
- We must meet the challenge of international competition in space (a challenge we welcome!).
- We must establish a permanent presence in space.
- We must move from an era centered primarily on space exploration to an era which includes the commercial uses of space.

These new challenges, when considered in their totality, constitute the beginning of a new era - the Space Business Era. They require that we reexamine, revitalize, and initiate imaginative new ways of doing business in two closely interrelated areas: (1) within the Government organization itself, and (2) in our joint industry-Government partnership. The Space Business Era will require Government to expand its space operations from exploration and experimentation to include significant commercial ventures as well. Such commercial ventures will call for a new kind of vendor-customer relationship between Government and industry.

An important reason for a permanent presence in space is the knowledge it will produce. Knowledge about many aspects of science, and the applications of this knowledge in technology development and commerce, will result from the enterprise of building a space station - a set of evolving, multipurpose facilities in space. The facilities envisioned for the Space Station include on-orbit laboratories; permanent observatories; a transportation and communication node; and servicing and repair facilities for spacecraft and manufacturing and assembly equipment. The Space Station is a means of acquiring and exploiting the unique knowledge and products which are made available through continuous access to the benefits of space, including microgravity, high vacuum, and being outside the atmosphere in low-Earth orbit.

A society which can produce highly productive, multipurpose facilities in space may be moving into a so-called "post-industrial society" on the Earth as described by Daniel Bell (Bell, 1976) and others. The "axial principle" of such a post-industrial society is the centrality and codification of knowledge. Other characteristics of such a society are a new "Intellectual Technology," the spread of a knowledge class, the switch from goods to services, a change in the character of work, and so on. The new intellectual technology for society will include artificial intelligence and robotics. The Space Station Program will both provide and use new knowledge, thus interweaving cause and effect. Congress has mandated that NASA advance the technologies of machine intelligence, robotics, and automation for increasing productivity both on the Space Station and in the U.S. economy. The Space Station Program, as both stimulus and user of this technology to achieve space-related knowledge/productivity goals, will provide a high degree of visibility to the technology.

For this business era of space, the fundamental challenge is to meet the needs of the "customers" (users of space) with facilities enabling maximum productivity and having low start-up costs and low annual operating costs. A facet of this is to minimize the role of humans as operators and to maximize their use as managers. An effective way to meet this challenge may be with a human-machine mix where robotics and advanced automation are integrated into high-reliability systems. Much of the technology required to meet the anticipated needs of the Space Station Program is not currently available. However, it is ATAC's belief that a vigorous research and development activity, if begun immediately, could produce the needed technology. It is largely this future technology base which will be transferable to U.S. industry and which will lead to productivity increases in terrestrial applications.

THE ROLE OF HUMANS IN SPACE

The environment of space is a difficult one, but the promise it holds for new knowledge and new products is immense. Further, there is a great deal we do not understand about either the environment or the potential. It is in just such uncertain circumstances that humans function best.

So, what then is the role of humans in space? The human role should be based on what humans do best, which is use their intelligence to perceive, to understand, to redefine continually what needs to be done on the basis of what has been learned, to take advantage of unforeseen opportunities, to solve unforeseen problems, to save a mission (occasionally), to supervise machines, to adapt with minimal reprogramming, and to acquire, integrate, and interpret multisensory data.

DEFINITIONS

It is useful to define some key terms which will appear throughout the document. "Automation" and "robotics" are much-used, broad terms. However, the fields of automation and robotics have grown from a blending of many technologies, including computer science, sensors, mechanisms, displays, and controls. Therefore, the terms will have somewhat different meanings depending upon the context. For the purpose of this document, we will use the following as working definitions.

Artificial Intelligence is a subfield of computer science concerned with the concepts and methods of symbolic inference by a computer and the symbolic representation of the knowledge to be used in making inferences so as to make a machine behave in ways that humans recognize as "intelligent" behavior in each other.

Automation is the use of machines to control and/or carry out processes in a predefined or modeled set of circumstances without human intervention. Advanced automation, for the purpose of this report, is used to refer to the fields of artificial intelligence, teleoperation, and robotics.

Autonomy is an attribute that allows a system to operate to its specified performance without external intervention for a specified period of time. Fault tolerance and reliability are key features of autonomy.

Expert Systems is a subfield of artificial intelligence concerned with developing computer programs that use knowledge and reasoning techniques in specific problem domains to emulate the decision processes of human experts.

Robotics is the study and use of machines capable of manipulation and/or mobility with some degree of autonomy. The autonomy may be almost complete - as in the case of an industrial manipulator which follows a sequence of preprogrammed moves, or the Viking Lander which carried out sequences of operations during the periods between instructions - or limited, as with teleoperators used for nuclear or undersea operations.

Teleoperation is the study and use of manipulators which receive instructions from a human operator and perform some action based on those instructions at a location remote from the operator.

Telepresence describes a teleoperation situation in which the operator has sufficient cues to feel present at the remote location.

The goal of an evolving, multipurpose facility for producing and using knowledge in space requires an evolving human-machine mix where the machines embody combinations of artificial intelligence, robotics, and teleoperation. The need for an evolving mix is based primarily on (1) the need to redefine continually what needs to be done and how often, on the basis of what has been learned and (2) the need to redefine the roles of man and machine as a result of growing confidence in the machine. Growth i the role of machines may continue from initial operational capability (IOC) to full operational capability (FOC).

This volume includes a list of acronyms and abbreviations, a proposed NASA glossary of terminology in automation and robotics, and a short list of some special terms or jargon peculiar to space systems.

NEED FOR AUTOMATION IN SPACE

The Space Station will, in any event, be highly automated if it is to succeed. A strong thrust to incorporate advanced automation and robotics can increase productivity, lower operating costs, increase flexibility, improve reliability, make an autonomous station feasible, perform tasks unsuited to humans, and reduce hazards. These benefits are achieved in three basic ways: by taking over time-consuming tasks that must otherwise be performed by the crew, by improving the level of performance of those tasks that are still performed or controlled by the crew, and by performing tasks that cannot practicably be done by the crew. The need is addressed in seven categories - productivity, cost, flexibility, reliability, autonomy, suitability, and safety.

Increase Productivity

A major rationale for advanced applications of automation on the Space Station is that it will increase the productivity of the crew. An astronaut in space is a very valuable resource which should be used to best advantage. Automation will not lessen the importance of the astronauts; rather, it will enable them to function more productively in space.

One way automation can help is by freeing humans from repetitive, tedious chores - for example, the many control and monitoring functions to be carried out on the Space Station. Advanced automation methods can take over much of the burden of monitoring and control. Astronaut assistant programs can be used to guide an astronaut through a complex technical task by providing facts and procedural information that would be difficult to remember. For repair of an onboard computer, for example, such a system might contain a data base of design information, suggest tests for the astronaut to try, and present procedures for recovering from the failure. An onboard, computerized inventory-management system can simplify the task of searching for equipment and materials stored on the Station. A corollary to releasing the crew from low-level control and monitoring functions is that morale will be enhanced, and the astronauts will have more time to devote to higher-level decision making and discovery functions.

Another way automation can result in higher productivity is by reducing the need for frequent, detailed control and direction from the ground. If astronauts are more closely involved in planning their own day-to-day activities via an onboard, interactive scheduler, they can make maximum productive use of their time. When communications with the ground are interrupted, productive operations on the Space Station need not be halted if a high degree of automation is present.

With automatic fault diagnosis and recovery, many component failures can be quickly and reliably detected and backup units placed in operation at once without disturbing the crew. The failed unit can then be replaced or repaired when convenient without disrupting the planned work schedule.

The Space Station will carry many sophisticated and complex devices. For humans to interact efficiently with these devices, the interfaces must be natural and direct. For example, "heads-up" displays, perhaps mounted on helmets and with voice input and output, would leave astronauts free to move about and use their hands while directing a machine. Displays, supported by intelligent data management, could reduce the apparent complexity of an onboard system by presenting data from the system in a condensed, visually informative manner. Developments in the areas of computer graphics, intelligent data base management, natural language, speech synthesis, and speech understanding will be used to accomplish this.

Productivity on the Space Station can also be enhanced by mechanical devices which interact with humans. For instance, a teleoperated or robotic system could be used to assist an astronaut on EVA by holding tools, moving objects into position, grasping objects being worked on, or providing mechanical capabilities a human does not possess.

Lower Operating Cost

Advanced automation can reduce operating costs sufficiently to justify easily and quickly the initial investment. In addition to enhancing crew productivity, cost savings over the life of the station can be realized through lowering the amount of support resources on the ground and extending the lifetimes and versatility of Space Station systems.

Increased Station autonomy can greatly reduce the number of personnel needed for ground control. Intelligent computer-aided instruction can similarly reduce the costs associated with preflight training of the crew; in addition, much training could take place on the Station through embedded training systems. Automation of systems in space can reduce maintenance expenses and extend the useful lifetimes of such systems. Automatic control enables a system to be operated at peak efficiency. Automatic fault diagnosis, isolation, and recovery can allow a device or experiment to remain in operation after a failure without the cost of sending a human to perform repairs or returning the failed equipment to Earth.

Increase Flexibility to Support Innovation

Advanced automation can increase not only the productivity of the crew on the Space Station, but also can increase the flexibility of systems in terms of their capability to support innovation. A system designed for automation will of necessity possess certain characteristics which support technical change and innovation.

The computing power and data storage necessary for automation will be present if required by some new technology. Data communication paths and standard interfaces established for automation will increase flexibility. Modularity of design and interchangeability of parts lead to easier incorporation of new technology.

Improve Reliability

The reliability of the Space Station is characterized by the likelihood of a failure or process interruption, the way in which a failure or interruption occurs, and the effort and time required for the diagnosis, repair, and recovery from the degraded condition. Clearly, failure should be infrequent and graceful and restoration should be smooth and prompt.

While the increased complexity of a highly automated system can be expected to have an adverse effect on component failure rates, automation can improve system reliability in several ways. Systems for monitoring and control do not become tired or irritable as humans do. Software for automatic fault isolation and recovery can keep a critical system going until an astronaut has time to change out the failed part. Fault-tolerant computing leads to better reliability of all subsystems that rely on computers. In emergency situations, automated systems which respond very rapidly to a crisis can bring the system to a fail-safe condition before extensive damage occurs. The system can then be repaired safely and put back into operation with a minimum of "down time." Without automation humans may be placed more often in pressure-prone situations such as EVA and emergency maintenance in which there is an increased chance of error.

Achieve Autonomy

One of the key engineering guidelines for the Space Station is that it is to be operationally autonomous. Autonomous operation means that the Station could carry out normal operation for some finite period of time without contact with the ground. This will be necessary as insurance against emergency situations where some failure or natural phenomenon disables communications. Moreover, autonomous operations will greatly increase crew productivity because the need for communication with the ground is reduced. The Space Station polar platform will require even higher levels of autonomy because a crew will be present only for special missions. The automation techniques so developed will directly benefit the manned Station. As more functions become automated on the Space Station, more knowledge and control will be transferred from the ground to space, leading to a higher level of autonomy.

To achieve autonomy on the Space Station, automation will be required in several areas. Expert systems are needed to perform many monitoring and control functions requiring complex status analysis and automated decision making so that the Station is less dependent on ground support in these areas. Planning and crew scheduling could be accomplished using similar methods onboard. A health maintenance facility using automated diagnostic instrumentation could increase the ability of the crew to operate independently from the ground. Automated fault diagnosis and recovery are necessary to be able to handle routine repair operations without assistance from the ground.

Increased experience with autonomous systems has allowed clarification of some of the pitfalls in this area. A potential problem is the over-reliance on decision-aiding systems. A person unfamiliar with the system might blindly accept recommendations from the computer, possibly leading to improper decisions. Expert systems can be designed to avoid much of this problem by pointing out the line of reasoning that leads to a particular conclusion.

Perform Tasks Unsuited to Humans Alone

Many tasks can be performed better by machines than by humans. One reason a task may be unsuited for humans is that the task is dangerous, an issue addressed in the next section. Here we consider tasks that can be performed better by machines, either alone or in conjunction with a human.

Machines tend to be better than humans at continuous monitoring; performing precise, repetitive tasks; storing and recalling large amounts of precise data over short periods of time; computing; responding quickly to signals; doing many different things at the same time; and ignoring distractions; and not getting bored or tired.

Machines can be given perceptual abilities outside the range of human capabilities, such as detecting particulate, infrared, and microwave radiation; magnetic fields; absolute temperature; and audio signals beyond the limits of human hearing. In some cases the real world is represented in forms that are more readily interpreted by machines than by humans. For example, thermographs, sonar images, spectrographs, CAD/CAM files, and stress diagrams can be analyzed by machine more naturally than they can be mapped onto the human sensory space and understood by a nonexpert.

In space construction, large forces or long-term, repetitive motions may be required that are difficult for humans. Certain tasks may require more time than an astronaut can spend in EVA. In some cases a machine can reach spaces that are too small for an astronaut in an MMU. For contingency operations outside the spacecraft, a robot might respond much faster than a human because EVA preparation time would not be necessary.

Reduce Hazards

A final reason for automation on the Space Station is that it can reduce danger to human life.

An increased telepresence capability will reduce the need for sending astronauts on EVA, thereby decreasing the exposure to potentially hazardous situations. In some cases, as at geosynchronous altitude, exposure to radiation is a serious threat. An unmanned Orbit Transfer Vehicle (OTV) with a manipulator package would be an effective alternative.

Work environments in space can pose serious dangers to humans because of the nature of materials or devices involved. Certain fuels are highly toxic or volatile. Some facilities in space will involve extreme temperatures or pressures. Completely automating these environments would remove humans altogether from such potentially dangerous situations, and automatic fault diagnosis and response can reduce the dangers where the crew must occasionally be present.

Despite all precautions, there is always the possibility that accidents will occur. Accidents such as the breakage of a fuel line or an explosion in a materials-processing facility would create environments too hostile for human intervention. Intelligent, general-purpose robots could deal with such emergency situations without danger to human life.

THE STIMULUS FOR THIS REPORT

Congressional Mandate

Conference report 98-867 of the House of Representatives, 98th Congress of the United States, was submitted as documentation of agreements by the two Houses concerning funding for Fiscal Year 1985 (House of Representatives Bill 5713). Amendment No. 39 establishes the Advanced Technology Advisory Committee (ATAC) in conjunction with the Space Station Program. The ATAC is mandated to identify specific Space Station systems which advance technologies not in use in current spacecraft. Additionally, it is the intention of Congress that automation and robotics implementation will not only promote the efficiency of the Space Station, but, by enhancing the technical and scientific base, will also lead to more productive terrestrial applications. The official language of the bill requires submittal of the ATAC report on Advanced Automation and Robotics on or before a deadline of April 1, 1985.

NASA/Industry Coordination

NASA requirements for Space Station automation and robotics, coordinated with the U.S. industrial needs for more efficient production, can play a large part in bringing the country into eminence in these areas. Several factors will be emphasized in space development which heretofore have hindered the progress of automation in industrial applications. The lack of standardization in computer systems has been a principal deterrent. The deficiencies include nonstandard languages and disparate intercommunication techniques. It is felt that an impetus by the government toward more universal computer interfaces and software development capabilities, in support of Space Station requirements, will facilitate wider acceptance of automation by terrestrial industries.

Success in meeting Space Station objectives for fault tolerance and fault recovery techniques will provide a better understanding and acceptance of the benefits of automation/autonomy by the industrial community. The utilization of robots in industry involves considerably different technology in basic design and development; however, research in control techniques and artificial intelligence as they apply to the Space Station is readily exchangeable with ground-based industries. Similarly, the requirement for operator interaction with robots and teleoperators and the resultant interfaces will apply equally to industrial and Space Station implementations.

The NASA Automation and Robotics Panel, led by Cal Space, has been the vehicle for coordination with industry and academia and for communication of their needs and requirements to the ATAC. This panel comprises prominent members of the industrial and academic research community who utilize automation and robotics for research and applications. Universities, national research laboratories, aerospace contractors, nonaerospace industries, the Department of Defense, and NASA support the Panel with regularly scheduled meetings leading toward the preparation of the report "Automation and Robotics for the National Space Program." The panel's recommendations for technology implementation stem from considerable experience in the industrial marketplace and their study of the requirements for Advanced Automation and Robotics for both the IOC Station and the evolutionary Station envisioned for the year 2010.

Identification of New Technologies to Stimulate the Marketplace

NASA has a long tradition in the promotion of ideas and innovations which have resulted in new and improved goods and services for the nation. This promotion and "technology transfer" has, in general, been little recognized. In many instances such ideas have contributed greatly to the needs of the public. Only a small portion of the populace is aware of their origin, yet nearly everyone is affected. Styrofoam insulation is a classic example. Another example is the development of Nuclear Magnetic Resonance imaging techniques, which are now finding wide application in medicine. A voice-controlled wheelchair was made possible by NASA-sponsored advances in voice command systems. These, as well as many other developments, can be traced back to basic research which was performed by industry and promoted by the Government's quest for aerospace applications.

The Space Station will utilize additional new technologies and will develop further applications of existing technologies. In both cases, a stimulus exists for new products and services for terrestrial applications. The exact nature and value of these applications cannot be predicted; however, past experience, as in the examples above, makes it clear that they will come into being.

Chapter 2

AUTOMATION AND ROBOTICS IN USE IN EXISTING SPACECRAFT

Congress has mandated that the automation and robotics technology used in the Space Station should advance the state of the art beyond that used in existing spacecraft. This chapter provides a brief summary of the current state of the art in existing spacecraft. Our present space activities simply would not be possible without automation.

Automation in Earth-orbiting missions consists primarily of (1) fault-tolerant redundancy and readily updatable command sequences in unmanned satellites, (2) additionally limited teleoperators on manned Shuttle missions, and (3) full autonomy with some closed loops on interplanetary missions where mission response times do not allow direct real-time commands. The Viking Mars Project, in particular the associated Lander mission, represents the most complex example of full autonomy undertaken by NASA.

TELEOPERATION/TELEPRESENCE

The state of the art of teleoperation technology as used in existing spacecraft can be exemplified by the Space Shuttle Remote Manipulator System (RMS). Due to lack of dexterity and general-purpose utilization, it is a limited teleoperator. Also, the system does not possess the attributes of telepresence (force/torque reflection and other sensory feedback), although its operation is monitored visually or with TV systems. Force and torque sensors are essentially state of the art and could be implemented if desired. Controllers to accept reflected signal inputs to provide "feel" can be designed with available techniques. The "vision system" used with the RMS consists of out-the-window viewing supplemented by in-situ solid state TV cameras and split-screen CRT's.

Arm control is through a computer software program which translates controller inputs into arm motion. Controller inputs are via conventional spacecraft hand controllers. A supervisory control routine has been implemented which permits the arm to follow a predetermined trajectory. Collision avoidance software was not implemented because of memory limitations.

Other means of controller input, such as master/slave controller of the RMS, were evaluated and rejected because of space limitations and excess complexity.

ROBOTICS

The soil sampler on the Mars Viking Lander is the example application, on U.S. spacecraft, of a system with robotic attributes. An arm, through a preprogrammed sequence initiated by an external stimulus, could locate itself at various surface positions, acquire and retrieve surface samples, and perform trenching operations. About one hundred to several hundred commands were required for each sampler arm task (Soffen, 1977). These commands were developed from stereometric determinations of sample sites occurring in the Lander cameras' image data. Command sequences were verified in simulations using the Science Test Lander. Soil sampler arm motor currents were monitored for scientific interpretation of soil mechanical properties, but not for robotic feedback. The sample analysis system employed a preprogrammed branching logic which permitted decisions, based on data comparisons, as to which branch (or analysis option) was most appropriate to follow.

AUTONOMY/AUTOMATION

The extent to which a spacecraft can operate autonomously can be indicated by the number of different elementary functions the spacecraft can perform between commands given by humans. The trend of spacecraft automation using this indicator is shown schematically in figure 1, taken from Sagan, 1980.

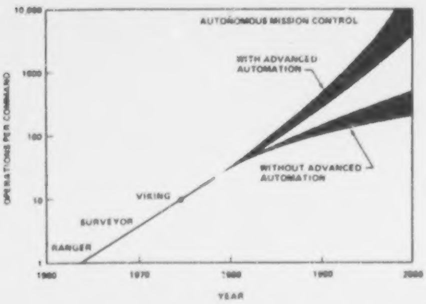


Figure 1.- Trend of spacecraft automation (Sagan, 1980).

In manned spacecraft vehicles, another relative indicator of the degree of automation is in the number and kinds of displays and controls available to the flight crew. The Shuttle Orbiter's Display and Control (D&C) system, which is a human/machine interface, is comprised of some 88 panels containing 1,660 control elements (circuit breakers, toggle switches, pushbuttons) and 646 display elements (meters, digital readouts, event indicators). Four multifunction cathode ray tube (CRT)/keyboard systems are also included. Three of these are in the flight deck panels. Historically, the complexity of spacecraft systems, including the D&C, has increased commensurate with increased complexity in mission and program objectives. For example, the Space Shuttle Program requirements dictate fault tolerance in all systems other than primary structure, thermal protection, and pressure vessels. The avionics systems, to achieve design life goals of 100 missions and 10-year-or-more operational span, are specified to be two-fault tolerant. In comparison, the Gemini (one-mission) spacecraft was controlled by a flight crew of two interfacing with only 286 control elements and 68 display elements mounted on 7 panels.

Other indications of the degree of automation, and ones which also impact the human-machine interface system, are the methods of fault isolation and system reconfiguration. Although the Shuttle Orbiter's avionics computers and sensor systems have the capability to sense faults automatically and reconfigure, the overall redundancy management of the spacecraft systems is largely manual. In fact, because of early concerns over problems of automatic reconfiguration such as generic software errors and "psychotic" computers, a requirement was imposed on the D&C system to permit the crew to manually inhibit or override any automatic redundancy-management actions.

Data Processing System Architectures/ Redundancy Methods

The state of the art in operational spacecraft is largely centralized processing with some level of functional or physical redundancy. A typical centralized architecture is that of the Space Shuttle which operates four computers in a redundant set. Each computer monitors the other's outputs. Voting logic in the set allows an errant computer to be voted off-line with the voting matrix communicated to the crew. The four primary computers all operate from the same software. Software redundancy, or the safeguard against generic errors, is provided for critical mission phases by a Backup Flight System (BFS) in a fifth computer. The BFS software was designed and coded by a group separate from the primary software supplier. Flight software testing is a major hurdle where a large number of changes must be accommodated. A start/stop simulation capability at the instruction-step level is critical for testing.

Some operational unmanned spacecraft and satellite systems are decentralized to some extent with processing dedicated to major functions such as command and control and attitude control. Fault tolerance is through block redundancy which can be active-standby, active-active, or both. For example, the Defense Meteorological Satellite Program (DMSP) satellite uses standby redundancy in most of its subsystems. The Voyager's

Attitude Control Subsystem uses an unpowered standby, whereas the Command and Control Subsystem (CCS) uses a powered spare to monitor the on-line unit. More decentralized, or distributed, architectures are appearing in developmental and planned spacecraft.

Fault Management

Test equipment is frequently built into hardware and software to detect failures or out-of-limit conditions. With physical redundancy, cross-checking permits one unit to monitor the primary controller (Voyager CCS) or multiple units to monitor each other (Space Shuttle Data Processing System). In instances where a level of functional redundancy is available in another system, the alternate system may detect possible faults in the primary system. For example, attitude may be sensed by a system with other primary functions and be able to infer information about the health of the primary precision attitude control system.

Ground procedures are used to detect and isolate failure. One such procedure is to require that special tests be run on the vehicle. Another is long-term trend analysis of telemetry or maintenance recorder data, which may be able to detect unit degradation or wear-out problems.

A technique commonly used upon detection of a fault in near-Earth satellites is to place the spacecraft automatically in a "safe mode." If, for instance, the spacecraft is powered by solar arrays, the arrays are pointed to the sun for maximum power and all nonessential power use is stopped. Ground analysis of the problem is employed to develop a most likely solution. The solution can be to switch to a redundant standby unit or to plan alternate operational sequences, or "work-arounds," that can be transmitted to the spacecraft. In manned systems, onboard manual reconfiguration has been routinely employed.

Automatic fault management is used in critical mission phases or in instances where it is essential to continue the nominal mission without loss of performance. The Space Shuttle's quadruply redundant computers will automatically vote an errant computer off-line. Avionics system sensors can also be reconfigured automatically. An example of the state of the art in planetary spacecraft is that of the undervoltage recovery function on the Galileo. The automated function, after detecting a system undervoltage condition, will reduce power usage. Then, for a particular mission phase, it will decide which power loads are appropriate and add such loads back on-line.

Space Shuttle fault analysis and isolation operations are largely manual. The Shuttle Orbiter has in excess of 3,700 in-flight measurement points of which 1,600 are displayed to the crew via dedicated meters and CRT displays; 2,700 are telemetered to the ground. To isolate a system fault below the level indicated on the displays, the flight crew and/or the ground engineers are required to refer to documents containing the detailed system schematics. Expert system technology, with its ability to provide complex logic traceability and analysis methodology in software systems, will materially reduce operational workloads and training requirements.

Extent of Autonomy

The first level of autonomy is generally considered to be "closed loop control." In such a situation, sequences of instructions are stored and executed upon initiation by a single stimulus. A higher level of autonomy is one able to operate on external information. For example, a device which scans the stars and automatically "locks on" a particular star provides information on spacecraft attitude - information which could then be used in a trajectory adjustment. These levels of autonomy with such "automated" functions are common on manned and unmanned spacecraft.

The expected growth of autonomy without intelligent systems is illustrated in figure 2 (Evans and Gajewski, 1985). This growth is correlatable to onboard computer capability, and may be exemplified by the Mariner vehicles which had five automated routines implemented in subsystem hardware. The Galileo spacecraft will have in excess of 200 automated routines, largely implemented by software. This growth in autonomy is closely

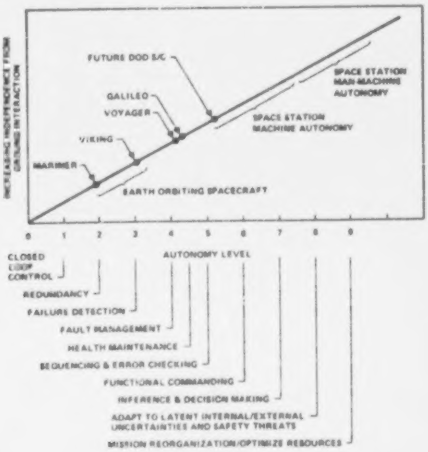


Figure 2.- Autonomy capability levels (Evans and Gajewski, 1985).

correlated to the computational capacity on the spacecraft. In the case of Galileo, about 10 percent of the vehicle's computer capacity is used for automated routines. A similar trend is found in the manned spacecraft program.

AUTONOMY IN EXISTING INTERPLANETARY SPACECRAFT

The Viking Mars Project is NASA's most ambitious achievement in fully autonomous missions. The need for full autonomy in all phases of mission operations was dictated by mission response times of 1 day to 2 weeks. The Viking Landers are especially noteworthy as examples of autonomous operations because of the difficulty and diversity of the tasks which were automated. Even the critical landing sequence had to be performed autonomously with final descent control being exercised by the Lander radar and computer systems. An exposition of autonomous operations is quoted directly from Soffen, 1977:

"The landers were built so that they could operate completely autonomously. At the time of landing, the onboard computers had instructions for performing many days of operations if we were not able to command the lander. In such an event it would have carried out a complete mission, taking pictures, getting samples from a preselected site, analyzing them, recording the weather and seismometry, and relaying the data back to earth. Fortunately, both landers operated flawlessly, and this preprogrammed mission was overwritten beginning with the first command link. Many elements that could cause a total loss such as power, communication, data, etc. were built with redundant units to avoid any single point failure. This was fortunate in the case of Viking 2 when one of the battery chargers failed during cruise. Failure on each spacecraft of one of the command receivers has borne out the wisdom of redundant systems. It was recognized that besides providing the scientific data the cameras would become one of the major tools in solving mechanical problems that occurred. Indeed, this proved to be the case time after time when we had trouble with the mechanical parts such as the sampling arm and the antenna.

"One of the most important requirements for performing the lander part of the mission was the ability to respond to the data. Since virtually nothing was known of the local surface topology, chemistry, or biology prior to the Viking landing, it was essential to be able to modify the experiments as they were progressing. This is the very nature of exploration and the place where the scientist plays a vital role. Our ability to receive data, interpret it, and make changes in our planned strategy normally required about two weeks. That was the time needed for preparing the software, for checking it to prevent errors that could be disastrous, and for sending and verifying the commands. (Of course, laboratory and field science on the earth is done differently, but one must remember that the automated laboratory is over 400,000,000 km away, operating by itself with our ability to command it only once a day at best!)...."

Autonomous operations of the Viking Orbiters were considerably less complex. These are summarized by the following quotation on command and instrument operation from Snyder, 1977:

"The computer command system (CCS) consists of two identical and independent data processors which receive and store all commands from earth and control everything that the spacecraft does. Each processor contains a 4096 word memory, and for data acquisition sequences, only one processor is used. This relatively large memory and the capability of reprogramming it during flight give to Viking the capability for much greater flexibility of observation sequences than any of its Mariner antecedents had. The memory is partitioned such that a maximum of 1500 words are available for each command load of ground commands to operate the orbiter, and during the primary mission it was the rule that initial planning would use no more than 1200 of these. Since it was not feasible to predict in advance precisely how many command words would be required, this limitation assured that the command generation process could proceed expeditiously and that planned observations would not have to be dropped at the last minute because they would not fit.

"The command words not only must specify how, when, and for what duration each of the science instruments operates but also must control the motions of the scan platform, any spacecraft maneuvers that occur, the tape recorders during both recording and playback of the data, and any switching between celestial and inertial attitude reference that may be required by the intermittent presence in the star sensor of stray light from Mars, Phobos, or Deimos. The command word limitation is usually the factor that constrains the quantity of observations that can be made. (**COMMENT:** The author notes the exception to this is the picture quantity which is limited by tape storage and telemetry. This observation occurs later in a portion of the text not quoted.) *This constraint was fairly comfortable when command loads were 2 days apart at times during the primary mission but quite uncomfortable for 4- or 5-day loads; when loads were separated by a week or more, very large gaps in the desirable coverage of the planet must be accepted.*

"The detailed sequencing of the orbiter science instruments is accomplished by the flight data subsystem (FDS) in response to the general instructions of the CCS. The FDS performs all the data handling for all orbiter subsystems...The FDS controls data acquisition modes, data rates and formats, gains settings, etc. From every subsystem it receives data, converts them from analog to digital, combines them with other data in the proper format, and routes them to storage or to immediate transmission...."

The use of autonomy in other interplanetary spacecraft is largely through the execution of a set of established procedures or algorithms or through onboard fault management techniques. The following discussion emphasizes procedures onboard recent interplanetary spacecraft.

The intelligent operation of a spacecraft involves a cycle of decision making, given the current state and the goals of the system, and the execution of tasks needed to accomplish those goals. Decision making for a spacecraft is necessary in several areas. At the lowest level are self-regulating processes (attitude, temperature, measurement biases, etc.). Such processes are frequently excluded from the discussion of autonomy unless a degree of external intervention is necessitated by the lack of such features. Other autonomy applications are logical in nature, but also relatively simple, such as the selection of appropriate attitude reference sensors given the environment of the spacecraft. High on the scale of complexity are processes which require balancing a number of factors. For example, a very involved sequence of actions must be planned for complicated events like planet encounters and trajectory changes. A broad spectrum of processes of intermediate complexity can be cited.

The functions which have been made autonomous on recent spacecraft critical to the safety of the spacecraft have been those for which cost studies showed advantages to spacecraft implementation in comparison with ground-based operation, or those which were critical to the safety of the spacecraft and the accomplishment of its prime objectives. Among the specific items automated in current designs, at least to some extent beyond simple self-regulation, are fault diagnosis, reconfiguration and critical sequence recovery, adaptive attitude reference selection, and tape management.

The principal barriers to autonomy levels greater than this has thus far been the shortage of computational resources and the lack of adequate tools to assist in the implementation of autonomous behavior. Existing implementations have been coarsely crafted and imperative in nature, certainly not representative of the latest in artificial intelligence technology, but they have been effective because of the care and skill of their creators. The rather laborious approach involved is best illustrated by describing the extent to which current implementations have progressed relative to future expectations.

The abstract ideal implementation of an autonomous system would contain some seat of "intelligence" in which would reside a dynamic model of pertinent system features, measurements to monitor the system, a set of goals and restrictions, and the logical tools to infer from these components the best course of future action. In current implementations, many compromises to this ideal have been made. By far the most ambitious efforts to date have been devoted to the autonomous maintenance of spacecraft safety and prime objectives in the presence of faults. (This is not to be confused with various fault-tolerant implementations which rely on simultaneous operation of redundant systems. Such implementations cannot be applied universally because of resource constraints or impracticality, nor would they be considered autonomous.) The resulting software for current implementations contains no system model or explicitly stated high-level goals and constraints, but rather has reduced the abstract ideal to a simple set of "if-then" rules.

These implementations were accomplished essentially by a predecision methodology whereby engineers mentally exercised as many potential fault and recovery scenarios as possible using their understanding of spacecraft behavior and mission goals and constraints to arrive at an optimized set of test measurements and preprogrammed responses. That is, they anticipated the responses that an ideal system might have made to a variety of failure circumstances, and then simplified and combined these responses to the extent possible while maintaining a level of fault coverage deemed adequate for the mission.

The operational disadvantage of this approach is that the responses taken are often overreactions resulting in spacecraft performance loss or missed opportunities. Furthermore, coverage is incomplete, potentially causing unnecessary risk to the spacecraft.

Another disadvantage is that this is an expensive approach which has been stretched nearly to its capacity to deal with current spacecraft designs. Evolution of more complex systems will force a transition to autonomy implementations closer to the ideal. The technology to enable this is becoming available in the form of expert system development tools, more capable computers, and developments in robotics. These systems will show much more finesse and scope of application while providing an opportunity for substantial cost savings.

Near-term advances in onboard spacecraft autonomy resulting from this new technology can be expected in the following areas: expansion of self-regulation to virtually all physical plants in the system, autonomous navigation and maneuver planning, adaptive collection and screening of scientific data, and the autonomous execution of simple repairs to remote systems.

Table 1 gives descriptions of fault-tolerant algorithms that have been used on recent interplanetary spacecraft projects (including the yet-to-be-launched Galileo).

There is currently little automation in ground operations of interplanetary spacecraft, although this has recently been identified as an area that can receive considerable cost benefit from automation. Demonstration programs using expert systems in the areas of planning, scheduling, and diagnostics are currently available in NASA, but none of these programs are fully integrated into operations at this time.

TABLE 1.- FAULT-TOLERANT ALGORITHMS USED ON INTERPLANETARY SPACECRAFT

Algorithm	Description
CCS Errors Subsystem	Responded to anomalous Command Computer System (CCS) hardware or software conditions. Normally placed the CCS in a wait state (except during a Planetary Orbit Insertion maneuver).
Planetary Orbit Insertion Power Transient	Provided a means to continue CCS execution of the orbit insertion maneuver in the presence of a spacecraft power transient or attitude control electronics power changeover.
Command Loss	Assumed a spacecraft failure if a command was not processed in a specified number of hours. Systematically switched redundant element until a valid command was received by the CCS.
Roll Reference Loss	Responded to a loss of Canopus reference star by commanding a flyback and sweep of the Canopus tracker instantaneous field of view to search for the star within the tracker's field of view followed by a roll of the spacecraft to search for the star.
ACE Power Changeover	Caused a switch to the redundant Attitude Control Electronics (ACE) under specific fault conditions.
Battery Charger Disconnect	Monitored the temperature of each of two batteries during charging. Disconnected a battery charger from its respective battery if an over-temperature condition was detected.
Share Mode	Determined that the spacecraft was in a share mode and shed preassigned loads to allow the boost converter to boost the solar array voltage to the higher operating point.
Pressurant Regulator Failure	Detected a propulsion regulator leak and isolated the regulator from a high-pressure helium supply before the propellant tank relief valves could actuate.
Battery Discharge Monitor	Monitored discharge current of two batteries during occultation and configured the spacecraft to a safe state if state of charge was below a safe level due to loss of one battery.
Power Check	Configured the spacecraft to a safe power state in the event of an undervoltage condition, a main-to-standby inverter switch, or a CCS tolerance detector trip.
IRIS Power	Selected the infrared interferometer spectrometer and radiometer subsystem (IRIS) standby redundant heater unit if the prime unit failed.

TABLE 1.- Continued.

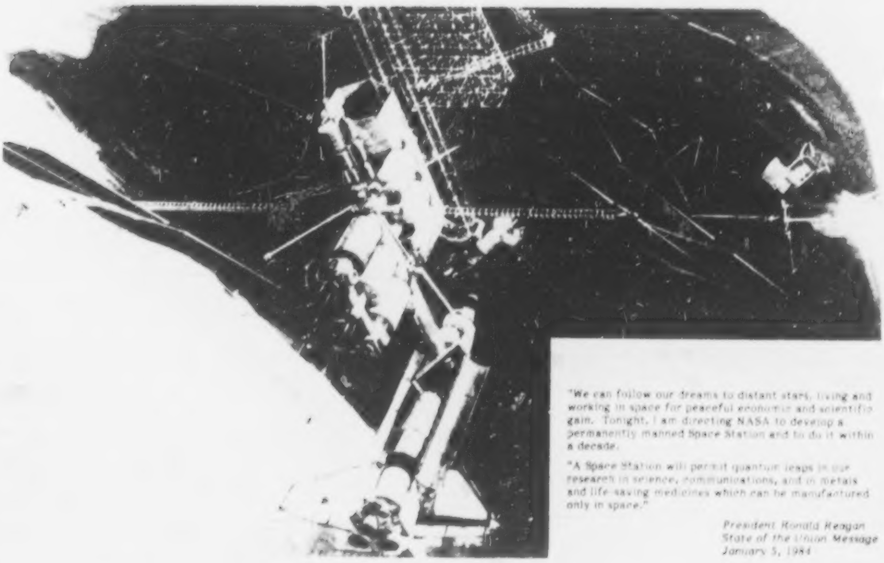
Algorithm	Description
AACS Power Code Processing	Allowed the CCS to respond to power codes from the Attitude and Articulation Control Subsystem (AACS). This was a "handshake" interface that allowed the CCS to monitor the health of the AACS computer and to respond to command redundant or peripheral hardware during normal operation.
Tandem and Turn Support	Verified the integrity of the CCS and AACS prior to critical functions, including turns and trajectory correction maneuvers.
Heartbeat Generator Self-Test Control	Provided a heartbeat check of the AACS-CCS and communication link. Also acted as a performance check on the AACS processor.
Omen Power Code	Issued a power code to CCS indicating detection of a serious fault in AACS. Resulted in saving subsequent power codes for ground analysis. Also inhibited certain functions such as trajectory correction maneuvers.
Celestial-Sensor Fault Detection/ Protection	Monitored operations of the sun sensor and Canopus star tracker. On detection of error, triggered the reacquisition of celestial references and swapped AACS redundant elements.
Autonomous Battery Charging	Autonomously recharged the batteries after solar occultation by monitoring battery temperature.
Science Power On	Prevented damage to science instruments from power transient at turn-on by monitoring current. The instrument was turned off if an over-current was detected.
Receiver Switch	Protected against a receiver failure during extended occultation by monitoring oscillator current and switching to the backup receiver if current fell below a preset level.
Downlink Off	Ensured that the spacecraft transmitter would be turned off at end of mission in the event of loss of command capability.
Accelerometer Monitor	Terminated on the propulsion burn-to-depletion test performed at the end of the mission by monitoring the accelerometer count and commanding engine shutdown when spacecraft acceleration dropped a preset amount.
Automatic Leak Clearing	Monitored position error to detect gas jet leaks and caused jets to actuate in an attempt to clear the leak.
Stray Light	Monitored the Canopus star tracker initiated sequences to prevent damage to the tracker and to acquire or maintain star reference after stray light exposure.

TABLE 1.- Continued.

Algorithm	Description
Low-Rate Engineering Telemetry	Extracted selected data from the telemetry stream for use in fault protection algorithms.
Radio Frequency Loss	Restored either S-band or X-band (or both downlinks) subsequent to a failure of either an exciter or transmitter.
Power Supply Fail	Checked power monitors in the AACS and initiated a swap of redundant elements if a fault was detected.
Memory Refresh Fail	Monitored the plated wire memory cell refresh performed by the AACS processor. Initiated a processor swap if the refresh process failed.
Trajectory Correction and Attitude Propulsion Unit Failure	Performed thruster pulse-rate and spacecraft angular position error checks to detect failures in thrusters. Switched redundant thrusters or AACS interface or processor units if fault was suspected.
Gyro Fault Protection	Monitored gyro warmup and compared outputs during operation to determine faults. Swapped redundant gyro and AACS elements if a gyro fault was detected.
Scan Platform Slew Fault Detection/ Protection	Software timer in AACS to detect slews which exceeded time allowed and prevented actuators from driving against stops. CCS response depended on frequency of fault occurrence.
Command Parity Fail	Performed a parity check in AACS on commands from CCS. If a parity error was detected, transmitted a power code to CCS and did not respond to the commands.
Command Sequence Fail	Protected against false commands to AACS/CCS interface and AACS processor and interface unit operation. Persistent absence of power code echoes resulted in swap of AACS elements.
Bad/No Echo Response	AACS power codes were echoed by CCS to test AACS/CCS interface and AACS processor and interface unit operation. Persistent absense of power code echoes resulted in swap of AACS elements.
Turn Complete and Maneuver Turn Abort	AACS aborted any turn if the sum of pitch, yaw, and roll exceeded 6°. Also rejected any turn commands if a turn was in progress.
Self-Test	AACS conducted a self-test of the processor on request from CCS. If unsuccessful, a processor swap was ordered.
Catastrophe Handler/ Processor Faults	AACS initiated interface unit and processor swaps if earlier switch to redundant element had failed to correct a fault.

TABLE 1.- Concluded.

Algorithm	Description
Propulsion Subsystem Over-Pressure	This algorithm protects the propulsion system from failures which can result in a large helium pressurant loss.
AACS Alert Code Monitor	This algorithm monitors the status of a number of attitude control conditions. A tailored response is provided for each alert code. Presently, 12 alert codes have been identified.
Temperature Monitor	This algorithm responds to the temperature of selected spacecraft elements and activates or deactivates electrical heaters to maintain proper thermal control.
Science Monitor	This algorithm responds to "ill health" indications from selected science instruments by deactivating the main power and activating the replacement heater power.



"We can follow our dreams to distant stars, living and working in space for peaceful economic and scientific gain. Tonight, I am directing NASA to develop a permanently manned Space Station and to do it within a decade.

"A Space Station will permit quantum leaps in our research in science, communications, and in metals and life-saving medicines which can be manufactured only in space."

President Ronald Reagan
State of the Union Message
January 5, 1984

Chapter 3

THE SPACE STATION PROGRAM

This section gives a brief overview of the Space Station Program (SSP). SSP elements and systems are described for both the initial operational capability (IOC) and the full operational capability (FOC). A preliminary operations approach is also summarized. Readers familiar with the SSP may proceed to Chapter 4.

BACKGROUND

The strength of the U.S. economy is closely linked to advances in technology. Keeping the economy healthy requires a continuing investment in new technology. One of NASA's reasons for existence is to preserve America's leadership in technology. The NSTS (Shuttle) has been a major step in technology leadership. Its development is complete and the system is now operational, providing the United States with effective transportation to Earth orbit.

The next logical step to build on previous national investments in space research is a space station. A space station also provides an opportunity for cooperative efforts with other countries. For example, it is a logical extension of the cooperative work with the Europeans on Spacelab. At the time the President announced his Space Station Program decision, he invited America's friends and allies to participate in the program. Thus, a major aspect of the program is to bring about participation of international partners as builders, users, and operators of the Space Station Program elements.

The Space Station Program will evolve in an orderly manner from an initial capability in the early 1990's to a much improved capability in the year 2000 and beyond. The indefinite life of the Space Station Program imposes a requirement for exploiting changes in technology. As new technology evolves and as new mission requirements are established, they will be incorporated into the existing system. Thus the Space Station Program design must be capable of accommodating such changes. As the Space Station Program capability grows, it will accommodate increased levels of autonomy and automation/robotics and attendant increases in human productivity.

The initial Space Station Program capability (NASA, 1984e) provides the following:

- Laboratory provisions for research, development, and demonstration in a pressurized environment with capability for continuous manned interaction and external attachments to which unpressurized payloads or pressurized modules may be connected
- Crew habitation provisions for a crew of six, including workstations, personal hygiene facilities, private quarters, and a ward room and galley that meet essential health and recreational needs
- Provisions for the supply and control of electrical power, thermal control, information and data management, communications, attitude control, and orbit altitude maintenance
- Provisions for berthing the Shuttle (National Space Transportation System) with the Space Station, for connecting major Space Station systems, and for storing and servicing the crew space suits
- Provisions for accommodating resupply of payloads and consumable items, facilities for crew hygiene, processing and storage of material, and payloads to be returned to the ground
- Attachment facilities at which satellites and an Orbital Maneuvering Vehicle (OMV) will be serviced, refueled, and stored
- Unmanned spacecraft (platforms), operated or serviced from the National Space Transportation System or Space Station,

that provide power, thermal control, information management, communications and tracking, attitude control, and orbit altitude maintenance for a complement of payloads

- Support services required to process and launch the Space Station, control the Space Station and platforms, provide customer data interfaces, and train the crew

REQUIREMENTS PERTINENT TO AUTOMATION/ROBOTICS

This section contains Space Station Program requirements that bear on automation and robotics. That is, the required function is a candidate for automation, or the requirement has a significant impact on the implementation of advanced automation. All of the requirements in attachments C-2, C-3, and C-4 of the Space Station Definition and Preliminary Design RFP should be considered in the advanced automation effort. The following requirements, extracted from the RFP, are the more pertinent ones for automation and robotics.

- The initial Space Station and Space Platforms must be designed to accommodate evolution to growth configurations.

- The growth Space Station must have facilities to support the on-orbit assembly of large payload structures, including associated attachment provisions.

- The Space Station Program elements must have the ability to remain operational indefinitely through periodic inspection, maintenance, and replacement of components.

- The Space Station Program elements must be designed to facilitate system growth through use of modular design. Common hardware, software, and standard interfaces which optimize benefit to the program must be employed.

- The Space Station Program elements must be designed to accommodate the incorporation of new technology as appropriate to benefit the program.

- A phased degree of on-orbit autonomy must be provided consistent with evolving systems and operations requirements, cost, and applicable evolving technologies. Platform design will facilitate autonomous operations between scheduled servicing periods but must not preclude ground intervention.

- The Space Station Program elements and subsystems hardware and software must be designed to facilitate on-orbit and ground maintenance, inspection, and repair with maintenance performed on-orbit to the Orbital Replaceable Unit (ORU) level.

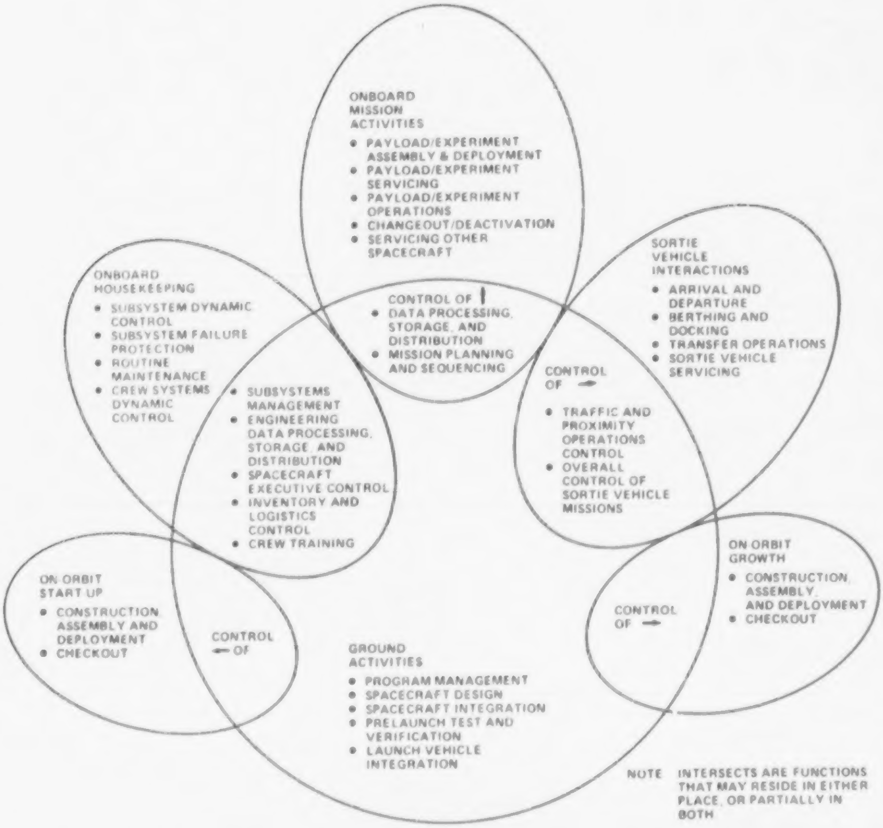
- The Space Station Program elements and subsystems hardware and software must be designed to provide for monitoring, checkout and fault diagnosis, and isolation to the ORU level without requiring removal of ORU's. For platforms, these functions must be automated, including corrective action response.

- The crew must be able to override any automatic safing or switchover capability of functional paths.

- The integrated logistics system must include an inventory management system for all Space Station Program elements and customers and must be accessible by both flight and ground systems.

It should be noted (Easter and Staehle, 1984) that no autonomous system is totally free of human supervision; autonomous systems do not replace humans in this sense. Rather, they provide much more flexibility for determining the optimal degree, nature, and location of human participation in space activities.

Figure 3 presents a general look at applications of autonomous systems by broad functional areas. Not all functional applications shown apply to every class of platform, but all would apply to multipurpose, inhabited, serviced, evolving platforms such as the Space Station.


ONBOARD MISSION ACTIVITIES
• PAYLOAD/EXPERIMENT ASSEMBLY & DEPLOYMENT
• PAYLOAD/EXPERIMENT SERVICING
• PAYLOAD/EXPERIMENT OPERATIONS
• CHANGEOUT/DEACTIVATION
• SERVICING OTHER SPACECRAFT
ONBOARD HOUSEKEEPING
• SUBSYSTEM DYNAMIC CONTROL
• SUBSYSTEM FAILURE PROTECTION
• ROUTINE MAINTENANCE
• CREW SYSTEMS DYNAMIC CONTROL
CONTROL OF
• DATA PROCESSING, STORAGE, AND DISTRIBUTION
• MISSION PLANNING AND SEQUENCING
SORTIE VEHICLE INTERACTIONS
• ARRIVAL AND DEPARTURE
• BERTHING AND DOCKING
• TRANSFER OPERATIONS
• SORTIE VEHICLE SERVICING
• SUBSYSTEMS MANAGEMENT
• ENGINEERING DATA PROCESSING, STORAGE, AND DISTRIBUTION
• SPACECRAFT EXECUTIVE CONTROL
• INVENTORY AND LOGISTICS CONTROL
• CREW TRAINING
CONTROL OF →
• TRAFFIC AND PROXIMITY OPERATIONS CONTROL
• OVERALL CONTROL OF SORTIE VEHICLE MISSIONS
ON ORBIT START UP
• CONSTRUCTION ASSEMBLY AND DEPLOYMENT
• CHECKOUT
CONTROL ← OF
GROUND ACTIVITIES
• PROGRAM MANAGEMENT
• SPACECRAFT DESIGN
• SPACECRAFT INTEGRATION
• PRELAUNCH TEST AND VERIFICATION
• LAUNCH VEHICLE INTEGRATION
ON ORBIT GROWTH
• CONSTRUCTION, ASSEMBLY, AND DEPLOYMENT
• CHECKOUT
CONTROL OF →

NOTE INTERSECTS ARE FUNCTIONS THAT MAY RESIDE IN EITHER PLACE, OR PARTIALLY IN BOTH

Figure 3.- Functional applications of autonomous systems (Easter and Staehle, 1984).

OPERATIONS SUMMARY

The Space Station Program will consist of flight elements and ground elements. Figure 4 illustrates the components of the Space Station Program for a mature Space Station.

The following ground rules provide a framework for the operational approach:

- The Space Station is intended to be manned unless unforeseen circumstances force evacuation.
- The Space Station System will operate in Shuttle-tended modes for material and crew resupply, for delivery of Space Station elements, and for delivery and return of payloads.
- Management of Space Station System operations (both manned and unmanned elements, will be divided between onboard and ground systems to utilize the capabilities of each most effectively.
- Communications between the ground and the Space Station System will be through the Tracking and Data Relay Satellite System (TDRSS) or its replacement system.
- Extensive preflight training will not be done for infrequent tasks (time-critical emergencies excepted.) Onboard training aids will be provided to assist in accomplishing these functions.
- Onboard flight operations will nominally be conducted 24 hours a day, 7 days a week.

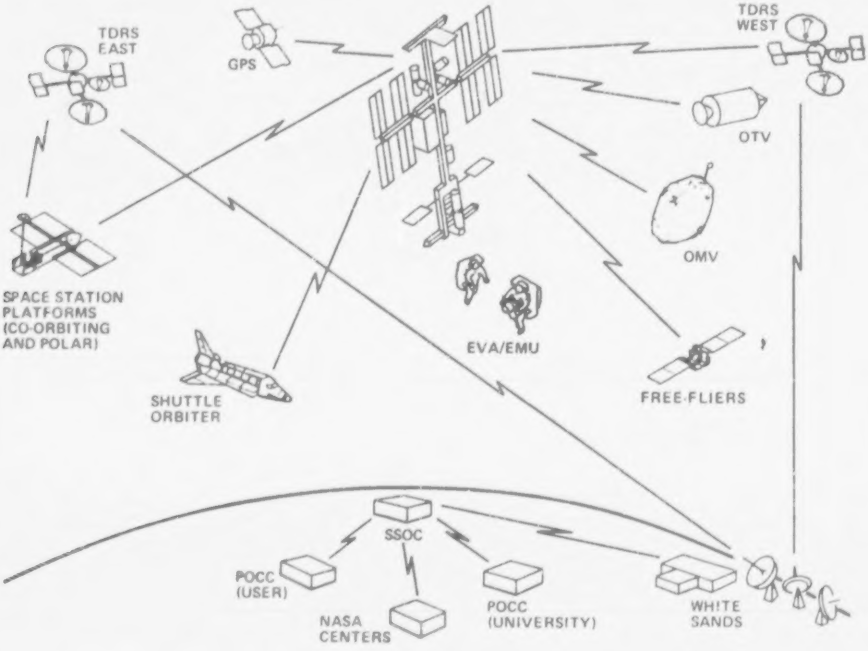

TDRS EAST
GPS
TDRS WEST
OTV
OMV
SPACE STATION PLATFORMS (CO-ORBITING AND POLAR)
EVA/EMU
SHUTTLE ORBITER
FREE-FLIERS
SSOC
POCC (USER)
NASA CENTERS
POCC (UNIVERSITY)
WHITE SANDS

Figure 4.- Space Station environment.

The Space Station System consists of platforms, free-fliers, orbital maneuvering vehicles (OMV's), shuttle orbiters, etc., in addition to the core station. Various ones of these vehicles must be capable of being flown to or close to the Space Station (proximity operations). The station will be the operations and supply base for these vehicles, with consumables, spares, payloads, and other equipment coming to the station in a logistics module carried in the shuttle orbiter. The OMV will provide the necessary orbital maneuvers to bring free-fliers or platforms into the proximity of the station for servicing if they do not provide their own propulsion. The OMV will also provide limited in-situ platform or free-flier servicing. Manned Maneuvering Units (MMU's) will provide EVA mobility within the region surrounding the Space Station. When the station reaches full operational capability, EVA activities will be minimized by use of teleoperated devices and, eventually, fully autonomous robots.

On-Orbit Operations

A major goal for the Space Station is to minimize both crew and ground control involvement in system monitoring through onboard automation and station autonomy. This will maximize crew availability for operations support and mission activities.

Mission activities include operation and servicing of internal and externally attached experiments and payloads, laboratories, and platform-mounted experiments and payloads. Also included are servicing of free-fliers, test and deployment of payloads and upper stages, OMV operations, and, eventually, operation of large-scale construction or assembly payloads and operation of OTV's.

The complexity of the station system makes planning a critical element of station activity. In general, there are two categories of planning, near-term and long-term. Near-term consists of planning daily activities for which information is onboard. This type of planning can be accomplished onboard the station and may make considerable use of an expert system. Some examples of near-term planning activities are experiments, general housekeeping tasks, subsystem status checks, payload mission planning, and preventive maintenance. Long-term planning is that which requires the consideration and integration of numerous facts and requirements to which the flight crew may not have access or that which can be accomplished more efficiently on the ground.

Ground Support

It is believed that ground control and support of the Space Station will always be essential and that, for IOC, such support may be extensive. Ground support is required for the station itself as well as the shuttle orbiter, payloads, OMV's, and OTV's. Initial ground control and support is in the form of flight and system monitoring and assistance during the deployment, assembly, activation, checkout, and verification of each new Space Station element.

The various configurations the Space Station System will go through during its evolution will require different levels of ground control and support. Ground support will be provided for the platforms, OTV's, OMV's, and the Space Station in the form of flight and system monitoring and assistance during the assembly, activation, checkout, and verification of each new station element. Ground support will continue until confidence is achieved in the new element's operation.

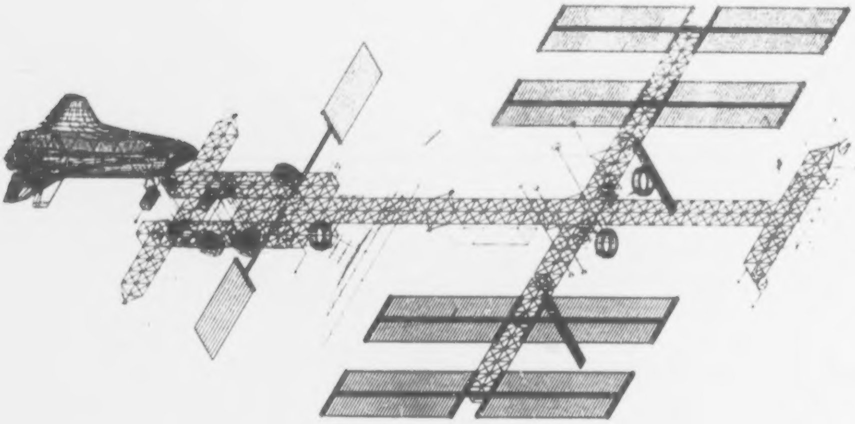
Mission planning activities for attached payloads may be done on the ground and/or by specialists onboard the Space Station. Control of attached payloads may be dictated from the ground, shared with the crew, or handled totally onboard. Payload operation and interactions with the Space Station will be conducted according to a schedule agreed upon with the customer. This schedule, or "timeline," will be maintained by the data management system (including elements both onboard and on the ground) and either the ground or onboard crew will be able to change the timeline.

The ground control facilities for the payloads (e.g., Payload Operations Control Centers) will be dedicated to the support of a specific mission. They are reconfigurable and are modified as required for each mission.

The payload ground control facilities, which are separate from the ground support facilities for the Space Station, should provide for autonomous operations consistent with those for the station itself. The payload support facilities will support payload checkout and performance monitoring, payload mission timeline planning, and a limited amount of payload data processing. Customers may use their own separate payload control facilities.

As operational confidence is achieved, ground control and support can be phased to an effective mix of onboard and ground involvement. A major application of automation technology to the Space Station is to minimize ground involvement with day-to-day station operation. The flight crew will be used for the performance of tasks where man's capabilities produce an effective alternative to automation. Autonomy and onboard automation will be emphasized as a goal to minimize ground control and crew involvement in system monitoring. Monitoring and control by either the flight crew or the ground crew will not be required for normal Space Station operations. In the growth station, automation of Space Station subsystems will free considerable crew time for support of payload operations and mission activities.

An additional benefit of station automation is to reduce the amount of crew training required. Training for crew members will be done on the ground and on-orbit. Customer training will be done primarily on the ground. The need for extensive flight crew training will be minimized, but the training must include system monitoring and maintenance; emergency procedures (including medical); housekeeping tasks; EVA, OMV, and OTV procedures; and construction and assembly procedures. There will also be specific training on individual payloads and experiments and cross-training to allow for a backup on critical tasks. Flight crew training will be as specific as possible, and training for infrequent tasks will be minimized because onboard tutorial and training aids will be provided.



Chapter 4

SPACE STATION SYSTEM DESIGN CONSIDERATIONS FOR ADVANCED AUTOMATION

This section presents Space Station Program applications for automation and robotics in a form directly related to the Space Station Reference Configuration (NASA, 1984d). After some general design considerations are introduced, including a systems approach to automation, conceptual applications of automation and robotics to selected Space Station subsystems are presented to illustrate design approaches which can be useful to follow in the Phase-B definition period. The conceptual applications represent new applications of automation and robotics in the reference configuration, and a summarized, but not exhaustive, list is included. Then considerations for Phase-B are given for automation of Space Station subsystems, operations, payloads, and experiments.

It should be noted that what is presented in this section is by no means meant to endorse, express preference for, define, or direct the efforts to any of the postulated subsystems amenable to automation and robotics. Indeed, it is not even certain that the conceptual suggestions are technically feasible - let alone practical - or that they are compatible with the exigencies associated with other Space Station Program elements. Other applications of automation and robotics in the Space Station Program may be uncovered by definition phase contractors that are far more worthy of consideration and are therefore encouraged. However, it is hoped that the suggestions presented here will stimulate thinking and that the suggestions are based, to a reasonable degree, on individual technologies which have at least been demonstrated, if not integrated into complete systems.

GENERAL DESIGN CONSIDERATIONS AND IMPLICATIONS

The potential for advanced automation on the Space Station includes almost all systems and functions. There will be an evolutionary progression toward realizing an increasingly autonomous and more productive Space Station. Therefore, initial designs must utilize as much mature automation as technologically feasible while not precluding eventual growth. The initial system design should conceptually be targeted for the mature, post-2000 Space Station and retreat from that position to IOC to ensure evolutionary growth. A primary consideration will be to achieve a design for subsystems which optimizes the human-machine mix of functions and skills. The designs should capitalize upon the strengths of both humans and machines. By approaching Space Station design in this manner, more of the long-term realizable advances in automation, intelligent systems, and robotics for the years after 2000 can be easily accommodated, once available. Furthermore, the necessary software "hooks" and hardware "scars" for the incorporation of such evolving technological advances will be in place in the initial designs to simplify the implementation at later dates.

It is critical that the initial design of the Space Station be tailored to the evolving technology of the future and not be so restricted that later system upgrades require wholesale redesign or total abandonment. Likewise, by designing the Space Station systems with the philosophy of distributed components and functions, the growth potential will be enhanced and there will be fewer single points of failure. Design for growth under such conditions is so extraordinary that some of the research to be undertaken in support of the Space Station should address such specifics as system design for growth in rapidly evolving technological environments.

Recent advances in computer technology allow increased use of artificial intelligence (AI) and robotics, which have the potential to greatly extend Space Station operations, offering lower costs and enhanced productivity. Expert systems astronaut assistants can help to lessen dependence upon ground systems, reduce mission costs, diminish complexity as perceived by the crew, increase mission lifetime, and simplify mission versatility. A highly automated system must amalgamate the diverse capabilities of people and machines to yield an efficient system which capitalizes on the unique characteristics of each.

The Space Station must also have an initial design which allows evolution to a more automated system. In the early years it is likely that artificial intelligence-based subsystems will be used primarily in an advisory or planning capacity. As human confidence in automated systems grows and as technology advances, machines will take on more critical and independent roles. An important aspect to be considered is the degree of system autonomy necessary for Space Station effectiveness. Expert systems utilize a significant amount of expert information about a particular domain to solve problems in that domain. Planning is the determination of a pattern of actions that can be carried out to achieve a goal. The advantage of current automatic planning systems over manual techniques are speed and easy comparison of options. Future automatic planning systems will allow more complex and detailed plans to be generated quickly and without errors. When the Space Station is first launched in the early 1990's, people will play an important role in almost all human-machine systems. Monitoring will be done by computers of limited "intelligence" (e.g., fault-tolerant systems with some rule-base expertise) but under human supervision. However in the post-IOC environment, much of the decision making control will shift from ground to the Space Station, and the crew will receive intelligent advice from onboard computers.

Many of the Space Station System and subsystem functions and tasks could incorporate an increased level of intelligence to yield a significant amount of autonomy. State-of-the-art techniques for fault tolerance, fault-isolation, self diagnosis, and self repair will likely be incorporated into the IOC systems. Knowledge of how to make systems "gracefully degrade" rather than experience hard failures will certainly have an impact upon all Space Station subsystems, even those with significant levels of automation at the outset.

Another important criterion is commonality. Commonality of hardware, software, and data protocols throughout the Space Station program will be needed, especially for connectors, software models, controls, control languages, and displays. For example, it is quite probable that most Space Station subsystems will incorporate some sort of microprocessing capability as the controlling entity within each subsystem. There is a strong argument for the consideration of a common component design, at least for a standard hardware microprocessor. For subsystems experiencing a nonrecoverable failure in a controller, a simple changeout with stock microprocessors could easily be accomplished by the crew. Software for a failed controller could then be loaded into a new controller from an interfaced storage device.

The incorporation of automation and autonomy on the Space Station is related to the interplay of cost, performance, and technology readiness. While it is highly desirable to enhance the operation or automate the performance of the Station, the costs associated with achieving the enhancement as well as the readiness of the technological support must be examined in detail. An in-depth evaluation of a particular situation might show that while it is not cost effective to automate a particular function on the IOC Station, "scarring" the IOC hardware for later ease of implementation of the function should certainly be considered for providing an eventual cost savings.

Designing for Autonomy

The Space Station should accommodate alternate configurations and readily allow for both additions to and deletions from an existing mission capability. The autonomy implementation approach should have multimission applicability so that it can be used for both manned and unmanned Space Station related needs, including diversified payloads and remotely located platforms at various orbital altitudes and inclinations. In addition, the architecture for achieving autonomy should accommodate advances in technology such that expert system and artificial intelligence techniques may be substituted for or added to current state-of-the-art computing techniques to allow increased levels of machine autonomy to be incorporated as a function of time.

All autonomous functions should be capable of being separately enabled, disabled, or updated under the supervisory control of ground controllers and/or the flight crew. This is necessary in order to ensure adequate in-flight maintenance, modification, and performance analysis. Furthermore, it allows a straightforward means for achieving executive control via ground operators, the flight crew, or automation. Such override capability by man should be tempered by the inclusion of protected command sequences in the autonomous mode. A protected command sequence should be employed in instances where the safety or operational capability of the Space Station might be seriously compromised if the sequence were interrupted during execution. The protected command sequence should warn external control sources about the dangers of sequence interruption but should still be capable of being manually overridden.

Current sensor data and autonomy-related Space Station operational status information should be maintained and made available upon request through memory readout to ground and onboard operators. This information would include the status of redundant subsystem elements, i.e., enabled, disabled, active, inactive, etc. Also, an audit trail or historical record of pertinent autonomous activities and resultant state changes should be stored and available for readout to ground controllers or flight crew members upon request. This will provide visibility to crew or ground controllers as to what has been done under autonomous control and the associated rationale for the actions. Sensor data will be required in conjunction with autonomy-related state information to interpret anomalies and evaluate operations. Key sensor data will also need to be recorded at frequent intervals. The audit trail will require correlated sensor data for interpretation. Autonomous control functions, including fault diagnosis, isolation, and recovery actions, should be accomplished with minimal disruption to normal Space Station operations for all mission phases. To accomplish this, the source of control (whether from onboard machine autonomy, the flight crew, or ground controllers) should be transparent to the Space Station user. Furthermore, the performance of autonomous activities should in no way adversely impact user-related payload integrity.

Test validation required for performing maintenance functions should be accomplished in parallel with normal Space Station operations on a noninterference basis. This would include the testing and calibration of redundant elements to maintain them in a ready state.

Any nonrecoverable fault associated with autonomous operations should result in a fail-operational and/or fail-safe mode. In the fail-operational mode, the Space Station would continue the mission in a degraded but acceptable level of operation. In the fail-safe mode, the Space Station would achieve a safe state and wait for crew or ground controller intervention. In addition, the autonomous system design should incorporate and provide multiple-failure tolerance for selected functions that are critical to successful mission operations and the safety of the crew.

Automated fault diagnosis, isolation, and recovery of many deterministic Space Station fault conditions should significantly enhance crew safety. Detection of unsafe conditions should automatically trigger warning devices such as alarms so that crew members can take appropriate safety precautions. Furthermore, the quick response times possible using machine autonomy should allow isolation and correction of many fault conditions before they can propagate and endanger the crew.

Self-test design features should be incorporated into both the hardware and software of the autonomous system to ensure proper operation even in the presence of internal faults. Internal faults should be isolated and corrected in a manner transparent to the Space Station functions being controlled. Furthermore, software health and maintenance algorithms should be designed to perform adequate diagnostics and verification prior to issuing warnings and hardware reconfiguration commands so that the occurrences of false alarms and "trial-and-error" redundant element switching are the exception rather than the rule.

Transient errors such as transducer glitches, bit errors, etc., should be accommodated by the autonomous system design such that they are transparent to the Space Station functional operation and configuration. Normal operation would continue with no interruption or degradation in operation, and no commands for reconfiguring redundant elements would be issued.

The implementation of autonomy design features should not introduce any single-point failures in the Space Station System design or significantly deplete critical Space Station resources that would degrade reliability. Furthermore, significant increases in cycling and stress of Space Station functional elements resulting in a decrease in component and/or system reliability should not be required by an autonomy implementation. Mechanical devices having inherent wearout mechanisms (such as tape recorders, in which lifetime is based on the number of start-stop cycles) should be given special attention in this regard.

The need to modify fault diagnosis thresholds can arise either as a result of incompletely characterizing the flight environment before launch (and thus having improper thresholds) or as a result of subsequent changes in the performance of hardware after launch. There should be a rigorous examination of all fault diagnosis thresholds in the context of the expected and actual mission environment. Dynamic environmental interactions deserve particular attention.

The autonomous system design should not effect changes in a Space Station state of operation that are not reversible. This could apply to hardware spare reconfigurations where it might be desirable to return to an original configuration if all the spares become exhausted or if the autonomy-related diagnostics did not result in an acceptable corrective action.

The autonomy system design should provide protection from erroneous commands from all human or machine sources. Although the flight crew and/or ground controllers have ultimate override supervisory control over the autonomous system operations, they must be forced to send valid commands. Therefore, the autonomous system should not accept or respond to commands unless they are valid, based upon criteria established as part of the end-to-end system design of the Space Station.

Designing for Growth

Classical retrofit of the basic station, some years after initial establishment, would in most cases be prohibitively expensive. And yet a central focus of Space Station design must be to facilitate the rapid future assimilation of new automation technology into the system, particularly in the technologically volatile areas of information processing, artificial intelligence, and robotics. This conflict can be resolved using nontraditional design features up front. The following are specific recommendations for such design features:

- Design environment to accommodate commercial and off-the-shelf technology

  In order to provide a cost-effective means of avoiding obsolescence of technology utilized at IOC for the Space Station, an overriding concern is that the station and its associated facilities must be designed to accommodate terrestrial technology and procedures. The Automation and Robotics Panel document stated this very clearly - "Buy, don't rebuild!" An approach that would allow this to occur would be to design the environment for the hardware needs so that industrial-grade technology and its terrestrial specifications can be utilized in space. For example, it may be time to reexamine whether it is more cost effective to build environmental control systems from commercially available hardware than to rebuild that same piece of hardware using space-qualified parts able to withstand the unattenuated space environment. A potential benefit from this approach would be a substantial reduction in the amount of time required for space qualification.

- Incorporate standard interfaces

  A cost-effective approach that is highly recommended is the use of standard interfaces for mechanical and electrical devices, sensors, and eventually robots. For example, provide standard umbilical utility connections pervasively both exterior to and interior to the Station to accommodate the needs of both astronauts and robots. The utilities provided at each standard umbilical point must include update access to the Station's computer network, as well as to power, water, oxygen, high-pressure gas, thruster fuel, etc. Also, provide standard attach fittings at each umbilical location and through the interior and exterior of the Station, to allow automated devices to temporarily restrain themselves in six degrees of freedom.

- Design for ease of assembly and servicing

  Since the degree of automation required for specific tasks is proportional to the task complexity, all aspects of the construction, servicing, and operation of Space Station elements should be kept as simple as possible. Designs of equipment need to be defined in such a way as to keep the number of steps required for assembly and servicing to a minimum. In other words, design parts keeping in mind that robots may be doing the assembly and repair in the future.

  The concept of modularity should be emphasized relative to the various Space Station elements. In particular, the concept of micromodularity deserves special attention. The idea is that large objects and structures be made from smaller, standardized, interchangeable micromodular parts. This would allow great flexibility in repairing and modifying structures, and it would reduce costs and delivery times as a result of standardization and simplification of logistic control. Another advantage, which is the theme of this report, is that it lends itself quite readily to automation, first by remote control and teleoperation and later perhaps by artificial intelligence methods as they evolve.

- Design for ease of identification and accessability

  Provide highly visible navigation markings and upgradable beacon systems (both internal and external to the Space Station) in such a way that astronauts and automated devices can easily determine their location and orientation relative to the station to minimize the cost of automated vision systems. These markings should be dual human/machine readable, such as standard OCR fonts or normal text plus standard bar codes or color coded insignia, etc. Use of special markings would also allow even currently available computer systems to keep track of all items and connection points. This would be extremely useful when new devices become available.

- Design for autonomy of routine deterministic operations

  Routine functions involving preplanned operations (sequencing, mode changes, configuration changes, etc.), management of deterministic a priori-defined fault conditions, and required maintenance of onboard resources should be performed autonomously in order to reduce the workload demand on the flight crew and/or ground controllers. Man's role in the performance of these functions would be primarily monitoring and supervision. This will allow more efficient application of human resources. However, the implementation of autonomous design features should provide for self-checking operations with performance monitoring so as not to add appreciably to the time required for in-flight checkout, initialization, and maintenance of the

Space Station System. Otherwise, the workload reduction realized from autonomy could be superficial.

Reducing man's workload on routine monitoring and supervisory tasks allows him to devote himself to tasks requiring greater sophistication. Autonomous monitoring and diagnostic functions should enable faults to be diagnosed earlier and propagation of the effects of faults to be reduced. Autonomous decision processes should enable more rapid and efficient responses to stimuli.

- Design an evolutionary computer system architecture

  Electronics evolution is a driver for computer technology. This is currently a rapidly evolving technology. As mentioned in the introduction, this area probably represents the greatest challenge when it comes to designing a computer architecture for IOC that is capable of evolutionary growth. The evolution of the computer system directly affects the evolution of operating systems, algorithms, computer graphics, computer simulations and artificial intelligence. Hence, care must be taken in the initial computer system design to ensure that smooth transitions between initial and evolutionary systems occur.

  The architecture must be able to accommodate advances in technology such that artificial intelligence techniques, e.g., expert systems, may be substituted for computing techniques utilized in the IOC design. There are three concepts worthy of note - central computer, hierarchy, and distributed. Each has its advantages and disadvantages, which are briefly discussed next.

  A centralized computer system uses a single central computer and some limiting processing ability in peripheral devices. Until recently, this has been the dominant design in industrial use.

  A hierarchy of computers is a development of the central computer design concept. There is something like a central computer at the top of the hierarchy. This computer is interfaced to second level computers, these to third level and so on. Generally, computers at the same level do not communicate with each other or to more than one computer at a higher level. The interconnections are thus tree-like, and the system is isomorphic to a logical partitioning of the algorithm to be executed by the top computer. As an example, the top computer may deal in terms of pilot commands, engine condition, and air frame condition, having each of these abstracted by a subordinate computer.

  A distributed approach does not include a central computer, nor does it restrict communication as does the hierarchical approach. Any computer in this approach can communicate with any other computer. This overcomes the rigidity of the hierarchical approach and permits free addition of units to the system, within engineering constraints. It increases the independence of the individual subsystems while requiring a simpler software executive for the central processor to schedule the largely autonomous subsystems. Also, this approach provides higher performance since the subsystem unique processing requirements may be performed simultaneously using parallel processors. It has the disadvantage of not modeling formal logic; it models a tangled hierarchy, making correctness and consistency checks difficult and intermittent error resolution formidable.

  None of these are really well suited to an evolutionary approach. The central computer is easier to replace than to modify, but replacing it would shut down the Space Station. A hierarchy would allow technology transparent interfaces at each mode, if properly designed. It would, however, not gracefully accept changes of station concept. A distributed approach has similar, although less severe, problems with complexity and change. For example, addition of a new unit can require that all existing units be notified of the name and abilities of the new unit and possibly how to use its abilities as well. This chore, together with a general lack of amenability to paper verification, may make modification of distributed systems difficult.

A candidate concept for consideration that would perhaps reduce the severity of the problems mentioned above is a hybrid system between the hierarchical and distributed system approaches. This system would employ distribution of the subsystem unique data handling and control functions but centralization of the system-level executive control functions.

- Incorporate CAD/CAE for accommodating artificial intelligence and robotics technology

Use of expert systems in the Space Station program has been identified as one very real application of artificial intelligence research. In conjunction with expert system development, considerable attention should be given to the use of computer aided design and computer aided engineering. At the very earliest time, design the Station-related CAD/CAE effort to couple and facilitate supply of information to expert systems. This couple is critical because so many expected elements of the Space Station are "model number one, serial number one." That is, there is no knowledge base to draw from except as created by the individual designers for each subsystem. It is essential to capture not only maintenance ideas from the designers but also reasons for such decisions. In addition, means must be provided for including later experience in the knowledge base. To allow the TMIS to develop without early couple to expert systems design activities may forever preclude use of this viable AI resource in many critical areas. Once lost, design thought processes can never be completely reconstructed. These considerations should also be extended beyond the design phase into configuration, inventory, and change-control during operations.

Designing for Ease of Communication and Cooperation With Intelligent Systems

In early stages of Space Station evolution, including IOC, artificial intelligence will be represented in elementary forms. The reasoning and intelligent control of systems by machines will be preceded by a strong reliance on man as decision maker. Automation and robotics will necessarily, and most productively, be applied in expanding and enhancing man's capabilities. Man will necessarily be more than ever "built into the loop." Thus, an apparent contradiction in design paths exists. Man will be provided more and more with subsystems to improve his productivity and tailored to his organic attributes. Artificial intelligence research, on the other hand, has as its aim the sharing and eventual supplanting of man as decision maker. Artificial intelligence currently resides in standard computers, or extensions of those computers, not unlike machines that will comprise the Space Station Data Management System. Computers serve as hosts for artificial intelligence for lack of anything better, not because computers, as currently understood, are best designed to implement the results of this research. As a consequence, it is unlikely that the Data Management System will either be amenable to early sizing to accommodate eventual artificial intelligence (excluding expert systems) or adaptable to the actual computational hardware which will eventually carry AI using standard or classical methods.

An approach which may permit sensible sizing of the DMS and graceful transition into the era of artificial intelligence might be by means of workstation technology (figure 5). The workstation could serve as the gateway for both man and artificial intelligence. Thus, design of the workstation must, at the outset, be more considered than the already difficult job of providing effective man/machine interface. In addition, this approach places restrictions on the DMS architecture in that direct access to required data and control be accessible at any workstation. A characteristic of this insertion approach is the gradual disconnection of the man as "do-er" in favor of man as manager.

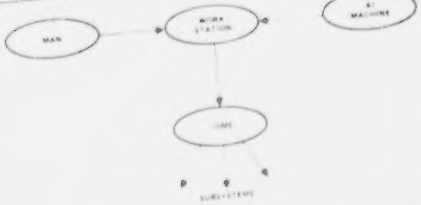


Figure 5.- Concept for growth into artificial intelligence via workstation as a gateway.

Technologies to be considered for workstations would be speech recognition and understanding, computer-aided vision (not necessarily computer vision), natural language computer input, heads-up display, data (information) fusion, advanced controller (joystick) input, three-dimensional (stereo) presentation, computer-generated images, reconfigurable control panels, and last, but most importantly, a standard interface for insertion of AI systems.

Left to happenstance and individual heuristic skills in the past, formal analysis and synthesis of man/machine interaction has become an important aspect of psychology and engineering work. From recent studies have come improved and more standardized automobile controls and instrument panels; vastly improved aircraft displays and controls; and computer architectures and workstations which greatly enhance the efficiency and effectiveness of software generation. Particularly in the case of the aircraft cockpit, understanding has been acquired relative to the placement of switches and displays to accommodate human anatomical constraints and mental context. As a result of this work, many previous causes of death have been eliminated.

The way in which humans interact with computers can have a profound effect on the productivity of software engineering. The Department of Defense has recognized this by creating a man/machine interface interest area under the Human Engineering thrust of the potentially $200 million per year Software Technology for Adaptable Reliable System (START) program. Likewise, it is funding the creation of user-friendly software through the development of its standard computer language, Ada. Both Ada and ATC UNIX operating system are examples of computing enhancements having human interfaces which are consistent across broad classes of machines and applications.

The Space Station, as well as other large and complicated systems such as nuclear power plants, will need computer-automated systems of control effectively interfaced to human operators functioning as high-level monitors and supervisors. The concept of supervisory control should be incorporated in the Space Station at increasingly higher levels from the highest available at IOC. Essentially, supervisory control will permit the human operator to input to the system high-level goals, after which the system will then devise a plan of implementation and set that plan in motion. The system also will be responsible for making available to the human, upon request, details of its plan and the logic used to generate the plan, as well as system status in goal accomplishment. The system should be designed to permit the human to intervene and assume control of any aspect of system functioning at any time and at any level. Thus, humans themselves will be able to replace directly the inappropriately functioning failed system parts at any time required. Under supervisory control, the system will perform diagnostics of its subsystems solely or optionally interactively with the human operator.

Although at the highest and most creative levels of planning, the human must become directly involved, the machine will even at this level handle most of the plan subparts which require such elementary processing as plan element sequencing to avoid conflicting constraints. Thus, the human can specify major plan segments which the machine will then plan in detail. At earlier stages of supervisory control, all planning may be done by humans who will request the system to merge in a specific sequence elemental, predefined sets or packets of actions; i.e., an action packet might be "grasp the beam" or another might be "translate the beam to x, y, z."

The implementation of supervisory control will require the development of displays and controls which facilitate human/machine communication, especially interfaces which permit the system judgment in presenting the human as highly processed and condensed information as will meet his needs or satisfy his requests. Thus, displays should permit the presentation of more-or-less detailed information as is appropriate. Voice communication (both input and output) should be researched and developed to very high levels of sophistication. Touch panel displays can be programmed to provide a very efficient interface, because they can present more readily grasped pictorial information while at the same time providing it in a hierarchically decomposable form. Thus, the operator could be presented a high-level block diagram of, for instance, the Space Station electrical power system. By touching a subblock of it, the operator could bring to full screen a block diagram of the touched subsystem. The touch selection could then be used incrementally to take the operator to the lowest required level of detail.

Although automated equipment soon will, for the range of functions for which it was designed, have capabilities similar to those of humans doing the same job, there will remain aspects of the job at which the machine is superior and others at which the human is superior. These advantages and disadvantages should be identified, and as policy a division of labor be made between humans and machines accordingly. For instance, humans are extremely good at recognition at which machines have great difficulty. On the other hand, humans have great difficulty precisely locating objects in space. Automated machines can be designed with sensors to do this quickly and well. Thus, interfaces need to be designed which permit humans and machines to readily request and supply complementary information of this type. Through these interfaces, then, the machine may ask the human, "What is the object I have zoomed in on on monitor 5?" Likewise, the human may ask, "How close is the antenna in the upper right corner of monitor 8 to thrust port 21 C?"

Development of more effective man/machine interfaces requires the continued development of powerful computers coupled to fast, large storage devices such as those which allow vocal man/machine communications. Artificial intelligence techniques along with knowledge-based systems coupled to large data bases will relegate human interaction to higher and higher levels as machines take over more and more of the detailed control of devices.

Complex digital computers allow displays which may be dynamically reconfigured to best present data to humans. Information indicating dangerous conditions may be presented in ways that enable rapid interpretation. Similarly, keyboards and other electromechanical devices will facilitate increasingly rapid control of machines. The effective use of these capabilities requires knowledge of how a human mind uses the data presented to it. The effective response requires knowledge about how humans can physically react. With such knowledge, displays and control devices can be optimized.

It is interesting to speculate about the future. One day, computers might be able to read the human mind and react to what is being thought. Even today, simple commands can be relayed by thought to machines. In the future, one will be able to have a computer supply answers and information without our conscious direction. On the positive side, this will free humans from the necessity of long training to coordinate visual stimulation and motor response. On the negative side, the computer could be used to introduce unwanted or unsolicited thought.

SOME POSSIBLE AUTOMATION AND ROBOTICS APPLICATIONS TO SUBSYSTEMS IN THE REFERENCE CONFIGURATION

In order to provide the Phase-B contractors with points for departure, it is the purpose of this section to suggest some of the ways that automation and robotics might be applied to the Space Station. Whereas the specific suggested applications are by no means meant to be exhaustive or in any way definitive, they do represent an approach for generating concepts and for identifying the specific automation and robotics technologies that could be brought to bear. The degree of maturity of specific automation and robotics technologies involved can then be assessed to determine feasibility for IOC or Evolutionary Station.

Since Phase-B has not yet begun, the only definition of the Space Station available is the reference configuration, defined by the Space Station Program Office during the summer of 1984. It is intended to be used as a starting point for the definition studies. The Reference Configuration has implications for automation and robotics which are described in this section. While the final configuration may differ considerably from the reference, it is likely that many of the concepts embodied therein will be retained. As a result, the following discussion of potential automation and robotics applications on the Space Station can be expected to provide examples of the differences between current technology and a reference minimum scope planned for the Space Station.

Electrical Power

The power system for the IOC Space Station may be either a photovoltaic or a solar dynamic system (NASA, 1984b; NASA, 1984c; and Fordyce & Schwartz, 1984). For a photovoltaic system, either regenerative fuel cells or batteries may be used for energy storage. A solar dynamic system can utilize either a Brayton or Rankine cycle energy conversion system. Additional power will be required for the growth Station. Both solar dynamic and nuclear power systems are especially attractive candidates for the growth Station because of low areas and high efficiencies. All of these candidate power systems are extremely compatible with autonomous robotic modes of operation, maintenance, and repair.

The long-term generation of power in space, regardless of the system, will require status monitoring and both preventive and repair maintenance. The type and frequency of maintenance functions will vary between the various systems (and their component parts) since each system will be subject to its own peculiar performance degradation and failure modes. Solar photovoltaic degradation can occur in many ways - micrometeroid impact damage, atomic oxygen attack, long term degradation because of space radiation effects, and possible surface degradation because of rocket plume impingement. In the case of storage systems, regenerative fuel cells are subject to different failure modes than rechargeable batteries. Solar thermal dynamic systems may also experience concentrator performance degradation because of the above phenomena (though probably to a lesser extent) and/or possible mechanical-electrical malfunctions in the dynamic machinery. Other problem areas include the thermal loops and the thermal storage medium. Nuclear systems with dynamic energy conversion systems could encounter the same failure modes in addition to reactor anomalies. Both the solar dynamic and the nuclear systems require large heat rejection radiator surfaces, which are subject to a number of possible failure modes.

Autonomous operation and robotics technologies are directly applicable to the status monitoring, controlling, and maintenance/repairing of these power systems. Automation and robotic techniques will reduce astronaut time for the operation and maintenance of these onboard systems. For systems such as solar dynamic and nuclear (with high-temperature and high-pressure hazardous environments in addition to the radiation environment of the nuclear systems), automation and robotics techniques will contribute to astronaut safety.

The required functions for the Space Station power system which will benefit greatly from the application of autonomy and robotics techniques are

- System monitoring, including state estimation, trend identification, and fault diagnosis
- System control/load management
- Automated maintenance
  - Inspection
  - Repair and replacement scheduling

The power system on the Space Station will be, in many respects, analogous to a terrestrial utility system. It must serve its customers (Station power users) just as a utility must serve its customers. Therefore, the operating practices of terrestrial power-producing utilities are in many respects, directly adaptable to "optimize" the operation of the Space Station power system. Fundamental concepts such as power plant dispatch, power system state estimation, and load management have been employed by utilities for many years. They are directly applicable to autonomous operation of the Space Station power system and are reflected in the automation and robotics technologies which will be adapted to the Space Station power system.

The above functions will be carried out at the component part, subsystem, and system levels, as required. The actual requirements will be determined by a detailed analysis of the power system.

In order to realize the benefits of automation and robotics technologies, the power system should incorporate into its design the features necessary to permit the above functions to be performed. Built-in test point sensors and instruments should be provided for data acquisition in order to accomplish system monitoring and statusing and state estimation of the system. For the repair, replacement, and maintenance aspects, the total system should be designed with a high level of modularity.

Monitoring - state estimation techniques. System monitoring will be accomplished by a combination of mechanical/optical inspections and electrical monitoring of built-in sensors to collect data on the status of the individual component parts of the system. The data will be stored in the memory banks of onboard computers. These data are then analyzed by means of a "state estimation" program which operates on the data in a way so that it can be used as an indicator of what is actually occurring in the power system (e.g., the state of the system).

For a photovoltaic system, the replaceable element may be an array section. Each array section may be provided with visual-electronic identification, including wired-in test points. The state estimation data banks might contain operating data on the individual arrays, including efficiencies, outputs, expected degradation with respect to time, etc. Many possibilities exist for array modularity. Instead of array sections, an entire foldable array assembly such as an OAST-1 or SEPS array (Lockheed array) may be the optimum level of modularity. A detailed system analysis is required to determine the optimum design.

For the energy storage unit (either a regenerative fuel cell or secondary batteries), the same logic applies. Data on the individual units can be stored for comparison with sensor data. The fuel cell or battery system might be designed at the orbital replacement unit of modularity. Within each unit, as with sections of a photovoltaic array, repair and/or replacement is not anticipated.

For the solar thermal dynamic system, the performance of the concentrator may be monitored by surface sensing devices, possibly laser beam instruments. By using these sensors, the degradation of surface coating optical properties, surface distortions, etc., can be determined. The performance of the entire active concentrator surface can be evaluated. The level of modularity might be a petal section or some other structural division. The status of the thermal medium and heat transport loops may be monitored at critical points by sensing the pressures, temperatures, and fluid flow rates. The dynamic machinery will also be fitted with appropriate sensors where electrical measurements (voltages, currents, and frequency) can also be monitored.

For the nuclear system, much of the thermodynamic-mechanical-electrical monitoring is identical to the solar thermal dynamic system. In addition, the reactor must be instrumented. The radiation environment must also be continually monitored to ensure the safety of the crew.

The power distribution system follows much the same pattern. Its status can be monitored electrically with sensors at selected points.

Trend identification. The status or "state" of the power system or any of its component parts will be determined by the state estimation program resident in the onboard computer. Comparing the estimated state with the expected state will give an indication of the system status. By maintaining a record of the estimated states, performance trends can be established for any level desired (system, component, etc.). Maintaining a time history of the performance allows trends to be established for predicting when component operations may become unacceptable and/or require maintenance.

Fault diagnosis. The state estimation program - by virtue of the data it compiles to determine system, component, or part status - can also be used in a fault-diagnosis mode. When the performance is degraded beyond a certain level, the state estimation program can identify the component part. Upon identification of the fault, the monitoring system can automatically switch to a mode for collecting additional data on the faulty component from lower-level sensors (which are provided but not normally recorded during nominal operation).

System control/load management. The Space Station power system might incorporate some degree of redundancy among its components and provide some excess capacity for output. For the solar-based systems in particular, excess photovoltaic or concentrator capacity must be provided in order to accommodate some performance degradation with time.

The information resulting from the state estimation system may be input to an "expert system controller." In nominal operation, the controller should maintain normal load management control. In those situations where performance degradations arise, the controller should try to maintain constant bus output by switching redundant components or by utilizing excess capacity, if available. If excess capacity is not available or if a serious power system failure were to occur (loss of one entire solar wing, for example), the expert system controller could carry out load management functions by rescheduling lower priority loads according to a predetermined scheme which has been based on estimates of future system performance.

For the case in which the energy storage system consists of high-performance secondary batteries, the controller may perform an optimum system charging function. Data on the individual cells might be stored in the onboard computer memory banks. Trend data on individual cell performance can be maintained and used to determine the optimum system charging profile to maximize the energy stored per charging cycle.

In conjunction with the load management function, an expert systems controller can be used to determine optimized repair/replacement schedules. The operation of an expert system controller can be much the same for either photovoltaic, solar thermal dynamic, or nuclear systems.

For heat-based power systems such as solar thermal dynamic or nuclear, waste heat utilization from these systems may offer significant advantages for reducing power, system mass, and/or electrical demands. The actual gains to be realized might be a function of the particular heat-using applications under consideration. Significant applications of autonomous control are possible here. An expert system controller, in its function as load manager, could determine waste heat availability and quality for (optimum) dispatch to the various using processes.

Another integration possibility exists if a regenerative fuel cell were used as storage for the photovoltaic power system. The outputs of a regenerative fuel cell, used in a regeneration mode (as an electrolysis unit), are oxygen and hydrogen. Cabin oxygen, needed for breathing, could be supplied by the electrolyzer unit if it is properly sized. An expert system controller could be used to determine the optimum mode of operation of a regenerative fuel cell employed as both an energy storage system and a cabin oxygen supplier.

Automated maintenance. Initially on the Space Station, EVA's will play a dominant role for maintenance, but teleoperations will be used occasionally. On the growth Station, automated teleoperator and mobile robotic functions will be used.

To ensure the evolvability of the Space Station, provisions for autonomous-robotics operation must be made in the IOC design. For the power system, the level of unit replacement, or modularity, must be a part of the system design. Connects and disconnects for all functions (electrical, hydraulic, and pneumatic) must be incorporated into the design at the replacement-module level. Module accessibility is also a prime design consideration.

Inspection. Upon detection of a malfunction, it may be necessary to employ visual inspections to determine causes and/or the extent of damages. This may be especially important for those components subjected to external influences such as solar panels, the solar concentrator, and radiator surfaces. In the early stages of the Space Station, astronaut EVA's may dominate, but fixed television or teleoperated television may also play an important role. For the more hazardous areas of the nuclear or solar thermal dynamic systems (which may be beyond fixed or teleoperated television range), automated mobile robots will be necessary.

For those components with uniform surfaces, such as solar cell wings, radiator assemblies, and solar concentrators, optical scanning devices could be designed as integral parts of these components for automatically scanning these surfaces. These would be mounted on carriages in order to determine the condition of the surface. The information obtained would be used by the "state estimation-expert system controller" to verify status, estimate performance trends, control related functions such as solar orientation and load management, and prepare repair and maintenance plans. Automated inspections of other components are also possible.

Repair and replacement. Like the inspection function, the autonomous robotic repair and replacement capability must be designed into the Space Station. Modularity, connectors, and access must be considered in the Station design.

For very hazardous situations, such as high-temperature or high-radiation environments, the robotic or remote operator system will greatly increase astronaut safety. However, the remote operator must be capable of withstanding these extreme environments. Also, provisions must be made to store the replaced units safely.

Operations. Automation and robotics technologies offer significant benefits to Space Station operations. Employing these technologies will result in significant reductions in astronaut time for operating, monitoring status, and maintaining the power generation system. Also, improved operations will result from using expert system controllers in evaluating options, schedules, etc., which are beyond the reasonable capability of an astronaut.

To support Space Station implementation of advanced automation and robotics technologies, the following technical disciplines have been identified:

- Teleoperations and robotics
- Pattern recognition techniques
- Optical inspection techniques
- System modularization design
- Advanced data display concepts
- Sensors and instrumentation
- Advanced, high-speed computers
- Expert systems logic development
- Integrated Station design concepts

The power system interacts with all other systems of the Space Station. Degraded or anomalous performance of the electrical power system will affect the overall operation of the Space Station. Highly complex interactions, requiring the analysis of a vast amount of data in a short period of time, are required to maintain optimum control of the Space Station. Expert systems and artificial intelligence logics will be used to perform these functions. Automation and robotic inspection and repair techniques are also required in some cases necessary for astronaut safety.

No impediments to incorporating automation and robotics technologies into the Space Station power subsystem are seen to exist. The process is expected to be evolutionary. In designing the Space Station electrical power system, consideration must be given to future autonomy and robotics requirements.

Guidance, Navigation, and Control

The Guidance, Navigation, and Control (GN&C) subsystem of the Space Station has many responsibilities, functions, and interfaces. An example of automation and robotics being applied to traffic control management, which will be addressed later, is an important function of the GN&C subsystem. This section presents some applications of automation in the other major subsystem function, attitude control. The attitude control function includes the attitude control of the Space Station itself, orbital maintenance, solar pointing, and experiment stability. It is planned that the Station be flown in a torque-equilibrium attitude such that momentum contributions from aerodynamic torque, gravity gradients, etc., total to zero for each orbit. Attitude control can be maintained by a momentum torquing capability of modest size. However, the flexibility of the Station structure may introduce dynamic control interactions which are more severe than experienced with any previous spacecraft attitude control system.

The Space Station Reference Configuration Document (NASA, 1984d) indicates the application of distributed computers to satisfy the many functional requirements; i. e., automation is already required by the nature of the functions. It is seen that the application of expert systems might be considered for identifying trends and for warning personnel of possible impending attitude control problems. The referenced guidance and control computer interfaces with many subsystems, such as star trackers, torquers, Control Moment Gyros (CMG's), actuators, and the like. It is very likely that improvements in many of these subsystems will evolve. For example, a "smart" star tracker may be developed that is capable of determining guide stars and navigational parameters, conducting self-calibration and making decisions about the information that normally would be processed by the guidance and control computer. Consequently, it is important that the design of these interfaces consider such developments and provide accommodating interfaces. Further, the subsystems should be designed for possible robotic replacement or retrieval and repair inside a laboratory module.

Operations of platforms, free-fliers, OMV, OTV, and the Shuttle in and around the Space Station will require a Space Traffic Control capability. Air traffic control (ATC) technologies and operations methods offer a large body of knowledge from which to draw. Taken together, techniques for RPV's and ATC offer a method for automating formation flying around the Space Station. The synthesis task, however, is further complicated by the requirement that orbital mechanics algorithms be added to the flight path control software for static station keeping and movement in and around the extent of the Space Station. An important element in a GN&C system for the Space Station is effective location and velocity information in the 8-kilometer sphere and forward and aft 30-degree cones called Space Station "area of influence" (see NASA, 1984d, p. 419, "Traffic Control and Proximity Operations"). Sensor systems capable of performing this function may have to be developed since Global Positioning System accuracy is insufficient to permit close-in maneuvers. Potential sensor approaches or techniques might be:

- Submillimeter phased-array radar
- Scanning CO-2 or Nd:YAG coherent or incoherent radars
- Collection of CCD TV cameras mounted around the Space Station with automatic

target identification either through beacons that are optically coded on the free-fliers or simple template matching computer vision recognition.

Some of the automation and robotics technologies involved with the guidance, navigation, and control subsystem are as follow:

- Sensing and perception (target identification)
  - Miniature radars
  - Laser radars
  - CCD TV cameras and coded optical beacons
- Advanced computers
  - RPV control system
  - ATC computer
  - Orbital mechanics algorithms for trajectories, etc.

For the Space Station IOC the identified technology development requirements include the formulation of orbital trajectory algorithms for near-Station EVA's. For FOC the technology development requirements include a collision avoidance sensory capability and an accurate trajectory planning and control capability. IOC hardware "scars" identified include the use of GN&C computers or computer networks which have been sized to accommodate the RPV and ATC orbital mechanics software plus I/O ports sufficient to control multiple free-fliers. Sensory systems will require the ability to add additional sensors to the Station elements as they grow. This will require the addition of ports with connections to power and data networks.

Communications and Tracking System

The communications and tracking system for the Space Station is quite complex because of the many communication users which must be simultaneously addressed (EMU, free-flier, OTV, OMV, platforms, Orbiters and TDRSS's) from the Space Station. The Space Station Reference Configuration Document (NASA, 1984d) describes the need for as many as 28 antennas for communication and tracking functions. The complexity of allocating usage of these antennas, scheduling, setting data rates for the associated modulators, and controlling the actual pointing for those that require pointing requires computer control that borders on the edge of expert systems, because the software will control the communication links by a priority scheme. Robotics can play a role in the replacement and repair of components, including the antennas themselves, because of their external locations (impact absorbers and convenient tiedowns), and the electronic packages involved in the communication and tracking system (such as the low-noise front ends, diplexers, switching networks, and pointing servos). This means that much thought must go into the design of subsystems, antennas, etc., to allow future use of robots to replace faulty components. Modularity is seen as the key to this requirement.

Communication with the ground via TDRSS may employ one or more movable dish antennas. As the Space Station moves in orbit, a switchover period from one TDRSS to another occurs. Whereas this may be momentary, high data rate sources will require scheduling and intermediate data storage in order to maintain continuity. Automation technology can be brought to bear when used in conjunction with advanced high-speed bulk data memory systems (in the DMS). The communications control subsystem may contain a scheduler that is fed information by the DMS regarding blackout occurrence and data transmission requirements. The communication control subsystem may generate a request for bulk storage during blackout, determine the amount of data to be stored, and restore the required effective transmission rate. If the data rate available is insufficient to compensate for the communication interruption, the communication controller could request rescheduling of tasks in the DMS master scheduler to yield no loss of data or perform some other corrective action. The addition of Multibeam Phased Array Antennas (MBPA's) could permit much faster switching to reduce interruption time. This would be expected as an evolutionary capability and could result in a single antenna for TDRSS communication. However, use of an MBPA might allow a multiple-beam antenna application and could benefit from a high-speed bulk memory scheduler operating in an effective multiplexer mode. The data rate for communication links might be increased to give constant effective Station-to-ground communication rates.

There are several automation and robotic technologies involved which have been identified and are listed as follows:

- Smart communication subsystem
- High-speed dynamic scheduler
- Advanced high-speed high-volume data storage in DMS or communication subsystem controller

One of the identified technological development requirements is the need for the storage of massive amounts of data. Two specific areas which have been identified for consideration on the IOC Space Station are

- Communication controller capable of intelligent interaction with DMS
- Provision for high-speed bulk data storage peripheral in communication controller or DMS

One identified critical interrelation with other Space Station subsystems for the tracking and communications subsystem is to provide a high-priority interface with the DMS during subsystem design.

Automation and robotics technologies which have been identified as being applicable to the communication and tracking subsystem include sensing and perception (including advanced displays to relate status, routing, and near-term schedules and computer vision for the detection of communication subsystem degradations or antenna blockage). Teleoperators and robotics are seen to have potential for the communications and tracking subsystem for repair and replacement of failed components. Advanced computers show promise for automated control of communication networks, data rates, data compression techniques, data link allocations, override control, and determination of data redundancy. Also, an advanced computer with a knowledge-based program could keep track of antenna pointing for establishing links. An expert planning system would provide a tremendous tool for the communication and tracking subsystem as a data transfer scheduler and controller. Technology developments are required in the areas of computer vision; robotics, for fault repair and replacement; expert systems, to automate link scheduling and control; displays, for presenting status to the crew; and speech recognition and synthesis, to achieve hands-free man/machine interface capability. IOC to FOC growth "scarring" should include component designs which would lend themselves to robotic repair, adequate sizing of computational facilities to allow for growth of expert planning and management, and design of antennas for high data rates at high frequencies.

The above considers the communications function of C&T. The other major function, tracking, is considered below.

The operations of the Orbiter, OMV, MRMS, MMU, EMU, and EVA will result in frequent mating of free-flying or unattached craft and berthing of various cargo with the Space Station. Two major subsets are indicated. The first includes those crafts or modules possessed of self-contained propulsion systems which are compatible with maneuvers in and around the Space Station (e.g., terminal docking Orbiter). The second includes those crafts or modules which are either unpowered or do not have fine control propulsion systems.

Powered craft may either be manned, controlled from the ground (perhaps via TDRSS), or controlled from the Space Station itself. Those vehicles controlled independently of the Space Station represent the most difficult to which to add automation in tracking and docking. The most beneficial level of automation applicable would be in a man-enhancing sense. That is, automation of subsystem tracking should be considered to yield information derived from advanced docking sensors (also compatible with closed-loop control), which provide an integrated simple display of target location approach rate, position error, warnings, etc., for simplifying the maneuvering procedures required of the pilot. Ultimately, an upgrade of the powered free-flier to closed-loop GN&C may be required in order to minimize docking shocks to delicate user equipment and/or to experiments and the Space Station structure.

Unpowered objects may likewise require tracking and docking, yet additionally require the function of berthing. The latter may be accomplished by the Space Station RMS devices but may also be effected by another device, such as the Orbiter RMS. Here automation technologies at the subsystem level (mentioned above) can be brought to full use by closing the loop from tracking sensors (and berthing and latching sensors) through the RMS control system. The information extracted from sensors in and around the docking and berthing area would not only be displayed but also be routed to the control system. Man could then perform the role as a monitor of events and intercede only if required by anomalous conditions. The key to providing automation in tracking, berthing, and docking lies in sensors capable of determining x, y, z, range, range rate (velocity), and orientation with respect to the desired contact location. Currently, only simple aids are available on the STS. Conventional RF radar is impractical at close range because of multipath interference, low angular resolution, etc. However, various new techniques such as millimeter/submillimeter radars may be applicable, while laser radars (coherent and incoherent) in various configurations have demonstrated good accuracy (1.0-millimeter resolution in 10-centimeter to 10-meter range) with the added advantage of high angular resolution. Orientation determination remains an area to be developed. Current concepts using retroreflectors at specified locations amenable to unambiguous orientation determination imply a considerable degree of cooperativeness in the target as well as human intervention to find and identify the target and set coarse target orientation. More productive techniques, which still require some human intervention, could be based on computer-stored sets of reference diagrams of the expected targets in line-image format. The stored information could be compared, in real time, with a line-extracted image of the target to yield orientation and distance. Computer vision systems are currently capable of extracting such line images, and a considerable capability to perform this task may already exist. A critical issue in this area is high-speed, near-real-time line-image extraction and comparison.

The automation and robotics technologies involved are sensing and perception (including advanced displays, proximity and pressure sensors, computer vision, and integrated sensor processors), teleoperators and robotics (including closed-loop robotic arms and closed loop GN&C systems), and advanced computers (including coordinate processors, optical disk technology and two-dimensional image correlators). Improvements in technology are required in the fields of extended computer vision, miniature high-power solid state lasers for extended target range and an uncooperative target acquisition capability. IOC to FOC growth "scars" include the provision at docking and berthing areas for CCD size TV cameras and miniature laser radar transmitters. Identified "hooks" include a control software and hardware environment which is capable of operating with direct sensor input instead of low-speed human joystick input. One critical interrelation of the communication and tracking subsystem with other Space Station functions applies to the Orbiter. An upgrade of avionics systems to provide closed-loop control of RCS is required for ultimate performance. No other critical interrelations are seen to exist.

Information and Data Management

The evolutionary growth of the Space Station and the short-term uncertainty of that growth demands a data management system (DMS) that is itself capable of evolving. Electronics systems should be added (or deleted) to meet changing Space Station requirements and to accommodate continuing advances in electronics, automation, and robotic technologies. One data system architecture which is thought to be capable of the evolutionary growth anticipated for the Space Station DMS is based upon local area networks (LAN's). This network should allow data system alterations to take place with a minimum amount of disruption to the normal operation of the DMS. The DMS LAN design should allow for the expansion of network capacity and performance to meet the projected requirements of the DMS if a major system overhaul is to be avoided as the Space Station approaches FOC.

A degree of fault tolerance is achieved in a LAN by a distributed architecture which provides multiple paths or routes between each pair of communicating entities. This allows information to be routed around or away from faulty network elements (e. g., broken links or down nodes). The network nodes, which provide an interface to the network for the attached systems, could be intelligent devices that execute distributed fault-diagnosis algorithms. These intelligent nodes would monitor the operation of their neighboring nodes to detect erroneous behavior (e. g., babbling devices or devices which place erroneous information on the network) as well as hard systems failures. Faulty systems (nodes or attached processors) would be isolated from the network and replacements could be switched onto the net if the failed unit is of a critical nature. After taking the appropriate corrective action, the DMS would file a failure report to a designated collection center attached to the system. These reports describe what measures are to be taken to bring the DMS back to full capacity. An integrated data network would support the core system and user/experimenter requirements of the Space Station in a unified network approach. One network might support all of the diverse communication requirements onboard the Space Station, thereby eliminating the need for several heterogeneous LAN's in the DMS. There is considerable interest in integrating voice, data, and video into one system in the U.S. (Dorros, 1983) for such applications as teleconferencing and in Japan for their future Information Network System (Kaplan, 1984).

A primary driver for an integrated services data network design is the performance required to handle video communications. A full motion video capability is required in the Space Station for rendezvous and proximity operations and autonomous systems. Therefore, the DMS should include fiber optics (FO) technology and high-performance nodes which can more effectively utilize the bandwidth inherent in fiber optics (15 GHz/km for single mode FO fibers). In addition, the incorporation of wave division multiplexing (WDM) into the fiber optic network design would allow various types of data (e.g., voice and video) to be transmitted simultaneously in full duplex over a single optical fiber (Hendricks, 1983). The limitations to the WDM technology, as well as to the performance of fiber optics in general, are the electro-optical and optical device technologies (transmitters, receivers, and multiplexers and demultiplexers). Presently, a 4-wavelength point-to-point WDM system is now commercially available (140 MBPS/channel) and an 8-wavelength WDM star bus has been demonstrated in the laboratory.

High performance in a LAN is realized not only by the use of high-speed devices and components but also by the selection of an appropriate architecture or topology. A topology that provides several alternate paths between each source/destination node pair (e.g., a partially connected mesh) can support multiple, simultaneous communications on the network as well as provide fault-tolerant operation. Conventional LAN topologies such as a broadcast bus or a token-passing ring do not possess such capabilities. In addition, alternate path topologies allow traffic to be spread out over the network (traffic balancing) to alleviate congested areas and reduce data delays. This is accomplished through the use of an adaptive routing algorithm embedded in each network node.

The design of efficient protocols for the DMS LAN is seen as a critical system requirement. Protocols which allow dissimilar systems to converse on a network should provide effective error and flow control at all levels. The ISO-7 layer model provides a useful guide for protocol design but attempts to standardize protocol layers which are directed toward less demanding and diverse applications than what are envisioned for the Space Station. Therefore, it is likely that the protocol design for the DMS will be tailored to meet the Station requirements, perhaps borrowing attractive features from existing standards. Once established, the network protocols will define standards for software interfaces at the higher levels and connectors and components at the lowest level. The lower protocol levels should be the responsibility of the intelligent network nodes. For example, they would be responsible for the delivery of error-free data from source to destination over the net. This would free the attached host systems to perform applications-oriented tasks.

Automation and robotics technologies which have been identified as having impact upon the data management subsystem include intelligent network nodes (electro-optic); robust fault-diagnosis algorithms; and high-performance network components, systems, and architectures. Technology developments required for the data management function include electro-optical devices (transmitters and receivers); optical devices (integrated optical switches, multiplexers and demultiplexers); integrated optical/electrical devices in monolithic GaAs circuits; high-density optical storage device with read/write capabilities; expert systems for configuration and control; and simplified distributed network algorithms. IOC to FOC "scars" relate to ensuring that the initial design of the DMS LAN includes the capability for expansion of capacity and performance to meet anticipated growth requirements.

The operations cost limitations and operations goals of Space Station are planned to reduce the many support personnel typically required to monitor, analyze, reconfigure, and checkout spacecraft digital systems in order to work around in-flight problems. Thus, there will be a need to automate the above tasks in order to attain the required Space Station autonomy.

Fault-tolerant design principles, using automated decision making, can be extended and improved with artificial intelligence techniques and applied at the levels of application software, operating system software, and hardware. At the application level there are often consistency relationships that are useful for identifying and, to some degree, isolating faults. At the level of operating system software, there should be fault-tolerant principles which can be used for fault diagnosis/isolation, state recovery, redundancy management, and function reconfiguration. At the hardware level, Built-In Self Tests and voting mechanisms should be used for handling faults. Audit trails for fault recovery actions need be provided at the system level for maintenance planning and scheduling and at the system/subsystem level for reconfiguration planning.

Typically, fault management is layered, and faults are masked to higher levels. Alternately, higher-level principles, such as analytical redundancy, can be applied to detect and isolate lower-level faults. Generally, higher-level reasoning is neither anticipated by nor passed downward to lower levels. A function of fault management would be to unify fault-tolerant information provided at various system levels (potentially an expert system with heuristic fault analysis of transient faults, trends, and critical combinations of design faults). Extensions of current fault management methods would make use of global information data to identify and isolate both hardware and software faults. It might also provide reliability analysis and maintenance planning, given the current context of fault data, system configuration, reliability, and mission requirements. The underlying layers of fault management itself would be highly adaptable, reliable, and subject to extensive validation.

The advanced automation and robotics technologies which are identified to be involved here include command/display in natural language interfaces, heuristic fault analysis, planning and scheduling, and self-improving tests and diagnostics. Technology developments which are required include representation of procedural knowledge, validation methods for autonomous reconfiguration, fault-tolerant software, reliability and performance analysis, and redundancy management. IOC to FOC "scarring" includes a provision for built-in test equipment. Software "hooks" include provisions for understanding and responding to fault management queries. In order to provide fault management with an adequate global view for diagnosis and planning, all systems with fault attributes (presumably all) would interact with fault management.

One of the most labor-intensive processes involved with NASA's projects to date has been the design, development, implementation, and checkout/verification of computer software. Automatic programming is a potential means to shortcut some of the long lead time and costs involved in the software development cycle. Automatic programming would allow projects to proceed from a specification of software requirements directly to an operational, thoroughly checked software package capable of performing its designated functions. Automatic programming is predicated on very basic but powerful concepts: having articulate knowledge of software organization (including structure, activities, policies, procedures, and responsibilities) and codification of knowledge in machine-usable form. Knowledge-based software program synthesis with iterative review, revision, enhancement, and validation at the program specification level is the paradigm of automatic programming. An automatic programming capability would be required to meet several basic postulates:

- Smart compiler
- Knowledge-based programming environment
- Self-description and, therefore, self-modification
- A knowledge base containing all knowledge on programming, the system, and project management
- One language (very-high level, wide-spectrum) for stating programs and knowledge

The Kestrel Institute of Palo Alto, California, estimates that an automatic programming facility could improve the software production cycle by a factor of 10 (Rockmore, 1984).

Propulsion

The resupply and maintenance of the RCS systems represent potential applications of advanced automation and robotics technologies. Resupply will require transfer of propellant or propellant tank modules between the logistics module, the Space Station, and the OMV and OTV. Means might be provided to perform or assist this activity remotely. The development of teleoperators, the employment of dedicated small RPV tugs, or the adaptation of the RMS mated to special-purpose coupling mechanisms should be considered to eliminate the need for EVA to connect/disconnect refueling supply lines. Connection lines could be fitted with sensors (including CCD TV's) and actuators to make them "smart" in the sense of being able to perform and verify the connect/disconnect functions, to detect leaks, and to perform at least some emergency safing procedures. In addition, on-station supply of propellent could be done at the thruster level instead of via plumbing. The RMS, a teleoperator, or (eventually) a robotic mobile resupply tanker could carry fuel around the Station for resupply of the individual thrusters. Such systems may also be useful for performing maintenance or for the removal/replacement of thrusters.

Some of the advanced automation technologies identified as impacting the propulsion subsystem are

- Teleoperator and robotics
- Special-purpose sensors/actuators
- Vision systems
- Mobile robots

New technologies required in support of the propulsion subsystem on the Space Station include special connect/disconnect couplers with integrated sensors and actuators, propellant gauging sensors, and advanced monitoring and control technology.

Hardware "scars" which might be effected on the IOC Station include the following:

- RCS systems having provisions for simple replacement capabilities
- RCS modules designed for ease of grappling by teleoperators or (future) mobile robots

One software "hook" which has been identified for the IOC Station is for propulsion fluids management, especially for Station center-of-gravity control. Such a controlling mechanism must also consider other Station fluids. Critical interrelations with other systems and subsystems of the propulsion subsystem include the DMS, which has the responsibility for resupply schedule, fuel inventory, and RCS status information.

Environmental Control and Life Support System

Environmental support for the astronaut crew will require considerable augmentation in capability over previously used space systems. Some elements of the ECLSS can draw on terrestrial experience for already developed technology. Other areas will have to be developed as part of the Space Station program. In particular, the ECLSS could be most effective if automation were incorporated in its control system. Crew time is better spent on higher-level activities than on servicing or tending an essentially static system such as the ECLSS. Nevertheless, crew safety considerations may limit the degree of ECLSS automatic control and autonomous processing allowed at IOC.

The monitoring function within ECLSS is an area in which advanced automation and robotics may be ideally suited for development of new technologies and applications. A considerable group of sensors have been developed which might well be considered for incorporation into a space station module atmosphere monitoring system. A representative example might include diode laser absorption spectrometers (which are capable of detecting minute traces of gases) integrated into an automated gas sampler. Such a gas sampler might be controlled by an expert system whose function it is to analyze the module air quality, detect incipient undesirable trends, and notify the DMS and/or astronauts. Water reclamation is another function which lends itself to a high degree of sensing capability.

ECLSS maintenance might require replacement or refurbishment of subsystem elements which potentially would be flagged by trend detections predicated on sensory inputs. As the ECLSS becomes more extensive (and more complex), expert systems could be utilized to perform the task of interpreting trends or conditions leading to maintenance tasks.

One application that might be considered for the evolutionary Station is an expansion of the expert system element of ECLSS to include an extensive trace gas leak identification capability (particularly for toxic gases). This capability might include suggestions as to where the likely source of the trace component might be, the potential toxicity, and the like. Implied in this is the need for an effective chemical or element composition sensor such as a Fourier Transform Infrared Radiometer (FTIR), laser abosorption spectrometer (LAS), or mass spectrometer.

The advanced automation and robotic technology involved in the ECLSS subsystem includes expert systems and an integrated air/water chemical analysis facility. One major "hook" for the Space Station growth from IOC to FOC is a provision for computer analysis and control of the subsystem which is more knowledge-based than is the initial design and for an integrated fluid management capability.

Thermal Control

The thermal control subsystem on the Space Station can reasonably be expected to be as operationally simple as possible for maximum reliability. Nevertheless, equipping the thermal subsystem with sensors and providing for replacement and repair of external thermal subsystem elements should be considered. Trend monitoring of performance at various points in the chain of parallel internal and external thermal transport loops can be used to determine maintenance procedures that should be scheduled. Special-purpose end effectors, or eventually robots, could incorporate (1) "sniffers" to locate leaks, (2) thermal sensors, and (3) repair kits equipped to repair leaks. Repair and replacement of thermal radiator elements would most probably be done by means of the MRMS or EVA. Degradation in surface coatings might also be amenable to repair via the MRMS EVA, or crawler robot (teleoperator). Electrospray paint refurbishment should be considered as a candidate technology for application to this as well as other Space Station functions.

The advanced automation and robotics technologies involved in the thermal subsystem include teleoperators with specialized end effectors plus sensors and perceptors. The required technology development for the support of the thermal subsystem is for a space-compatible spray paint adapter for teleoperated end effectors and thermal "sniffers".

Structures and Mechanisms

Mating of the Orbiter with the Space Station is an area that should be considered for automation and robotics techniques. The Orbiter will be required to rendezvous and dock with the Station on a regular basis, but it will also quite likely perform various maneuvers in and around the Station requiring multiple attachment to the Station. Several potential customer/user missions may not be able to accept the shock of hard docking to the Station, nor can the Station continually endure potential disturbances to the GN&C systems, or structural loading that might result. An Orbiter-automated docking or man-controlled docking mechanism should be considered for accommodating these constraints.

It it most likely that man will initially perform much of the assembly of the Station as well as (early) operations involving docking. However, as automation and robotics technologies mature and sensors and perceptors are developed to support more autonomous Station operations, it is anticipated that much of the docking and structure repair and refurbishment can be performed via teleoperations or autonomously by robots.

The identified automation and robotics technologies involved with the Space Station structures and mechanisms subsystem include:

- Sensing and perception (embedded CCD TV cameras, latching detectors, alignment sensors, etc.)
- Advanced workstations
- Actuators
- Teleoperators
- Computer vision

One major technology development which is required for structures and mechanisms is a flexible docking adapter. The Orbiter would have to be fitted with a set of mating points in the bay near the access area to support evolutionary growth of the Space Station in the post-IOC era.

Operational control of an individual space vehicle is a viable candidate for being highly automated on the IOC Space Station. Operations involving station-keeping (i. e., flying in loose formation in the near vicinity of another vehicle) have already been demonstrated to a high degree of reliability in operations involving small satellites. Previous operational space experience has proven the techniques necessary for automatic rendezvous and docking of two vehicles in space. An automatic rendezvous might be employed to bring a vehicle in close proximity so that the Space Station RMS could be used to ease the two vehicles together in the proper orientation to prevent bumping damage.

The portion of the structures and mechanisms section that deals primarily with automation would be the structural deployment verification and the use of the MRMS for the assembly of Space Station structures. Space Station construction represents an excellent opportunity for a robot/teleoperator to prove its worth in reducing the amount of extravehicular activity required to accomplish this task. Once it has been adopted that a truss system will be employed in the construction of the Station and a way has been determined for a manipulative device to move about upon that structure, then the exact method of construction can be ascertained. In the design of the Space Station, the attempt should be made to make things easy for interfacing to robots or robotic devices. Application of robotics to the Space Station may require that robot mobility be a central design consideration of both the utility/support structure and of all replaceable modules. Advanced automation (AI and robotics) can serve many diverse purposes and is acceptable across most aspects of the operation of the Space Station. There is, therefore, a logical argument for treating AI and robotics as a utility and making them a part of the utility/support structure. This should be avoided because of the rapid rate of change in this field.

Habitability

The Space Station must provide an internal environment adequate to support and maintain crew comfort, convenience, health, and well-being throughout all operational phases. The day-to-day operation of the inhabited environment of the Space Station should be highly automated with only occasional human monitoring required from IOC through FOC. Automation of the control of the environment in the Station will surely undergo further automation with the advent of artificial intelligence and expert system ideas being employed in the monitoring process.

In-flight health care is an absolute requirement for Space Station planning. On-orbit medical care will promote crew safety and maximize performance. An in-flight Health Maintenance Facility (HMF) could also prevent the unfortunate scenario of an unscheduled rescue mission for medical reasons. Health care will embody the triad of prevention, diagnosis, and treatment. Each will use biomedical equipment designed for the Station, along with medical procedures proven in microgravity and medical knowledge derived from terrestrial medicine. The facility must be modular to allow for quick changes in mission emphasis and also to allow for technology advances which permit more utilitarian equipment for diagnosis and treatment. Low-weight, yet low-volume, fully automated diagnostic laboratory equipment must be included in the HMF. Routine clinical chemistry, hematology, microbiology, urine analysis, and toxicological monitoring are essential. A capability must exist to deal with acute critical care and trauma situations. Real-time analysis of physiological parameters for assessing the health of the traumatized patient is a must. Computer-aided statusing of the patient is necessary. On the Space Station, the following health-care functions (and probably many others) should be automated:

- Medical history taking
- Instrumentation-derived data analysis (including real-time monitoring and analysis)
- Medical imaging
- Medical image storage and retrieval
- Medical decision making

The tremendous amount of information required for decision making in medicine and the importance of these decisions have led to investigations of computer-assisted medical decision making. The goals of artificial intelligence in this field are to obtain human-like behavior from a computer program, using symbols to represent the concepts and objects of the medical environment. Expert systems are designed to capture the specialized knowledge of practitioners whose performance is significantly above the norm. Unfortunately, the knowledge used by experts in their problem-solving tasks is not well formulated or well documented, specifically with regards to the medical experts. However, the computer can be used to a great advantage as a medical decision making aid.

Specifically, the incorporation of fault tolerance and fault isolation will significantly contribute to autonomy of operation. However, there is another aspect to habitability considerations for the Space Station beyond creature comforts, and that is the interface of the crew to the Station and its subsystems. Crew interface is important for several reasons. Knowledge is required by the crew to interface with the multitude of Station subsystems; it is highly desirable that this knowledge be made as transportable as possible from subsystem to subsystem in order to minimize the cross-training required to operate the various subsystems. A standard command structure or the like for all subsystems is probably not feasible because of the diversity of the applications of subsystems. Potentially, however, there is a way for the communication of crew instructions to subsystems to be universal in nature, and that is via voice commands and intructions. Such a system would necessitate an interpreter for speech to be a part of the crew interface of each subsystem. The technology requirements of such a speech interpreter are probably beyond today's state of the art. However, some of the ideas for a speech subsystem will be examined to explore the potential for enhancing Station habitability through automation.

Automation of hematological blood counts by specialized computer vision systems has been available as a part of commercial instrumentation in clinical laboratories since 1977 and should be considered for application to the clinical laboratory hematology section of the Health Maintenance Facility (NASA, 1984d, p. 90). Special machines which are based on cellular logic have proven to be a rapid means of automating white blood cell counts and may require additional development to perform other types of hematological analysis for quick-response medical diagnosis. Applications may exist for microbiological and chemical analysis as well. Rapid, automated medical diagnosis may be a critical issue in dealing with medical problems which require immediate diagnosis before the return of a Space Station crew member to Earth is either possible or medically advisable.

Computer vision and cellular logic machines and operations are the automation and robotic technologies involved in the habitability subsystem. Additional development may be required to extend current technology to broader hematological, microbiological, and chemical analysis applications. The one identified "scar" is for computational vision hardware in the Health Maintenance Facility. Further near-term development of cellular logic applications to medical clinical laboratory processes is an applicable IOC-to-FOC software "hook." Critical interrelations with other systems include the medical expert systems and the information and data systems.

Extravehicular Activity

Whereas the very essense of EVA and its man-intensive nature give pause to consideration of the applications of automation and robotic technologies, certain functions might be amenable to machine assistance. Examples that might be considered are automation in EVA suit cleaning and MMU resupply and maintenance, so that the procedures presently done on the ground can be done on-orbit without overloading crew time. Simplified subsystems for suits which are designed for easy replacement, refurbishment, and repair might be considered.

' Many aspects of inspection, monitoring, and proximity operations should be investigated by Phase-B contractors because man-machine partners possess capabilities superior to those of man alone for performing complex tasks which are beyond the reach of complete automation in the foreseeable future. In particular, the man-machine partnership inside the Space Station and in EVA should be scrutinized carefully. A man-machine partnership would combine the analytical and intellectual powers of the man with the quantitative skills of machine sensors and computers. An interesting case study would be man-computer vision. Astronauts will be supplied with EVA TV cameras, so video will be available to a computer which could be added to the astronaut's suit. The principal issue would be miniaturization of necessary computation hardware and man/machine interfaces. Functions to be performed by the computer would be to supply quantitative information on an object's size, orientation, and condition after an astronaut had identified the object or feature for the computer. As an example, the astronaut, inspecting for erosion in module walls, could point the camera to a suspected problem and ask the computer to supply engineering data on that module part; the computer would then calculate the area of erosion on the surface and supply information on the severity of the problem using engineering data baselines.

Advanced automation and robotic technologies which would be involved with EVA include a computer vision system. Identified technology needs required to support EVA automation include miniturized displays and crew interfaces. IOC "scars" may include a portable computer with appropriate astronaut interfaces. Software "hooks" in the IOC configuration include the specialized software for computer vision applications. One identified critical relationship of the EVA subsystem with other the Space Station subsystems includes a communication link with Space Station primary data base and an air-to-ground link for potential problem resolution.

Other areas which may be considered for advanced automation are the EVA support functions. The servicing of suits and mobility units could possibly be done more effectively by advanced automation and robotic techniques. Also, at least one air lock will be equipped as a possible hyperbaric chamber for emergency use. Automated control of this facility should be considered, as it will be essential for safety.

Verification

System checkout and verification have always been one of the most costly, time-consuming elements in any space flight program. Automation and robotic technologies offer the means potentially to alleviate some of the time and expense required to effectively check out and verify Space Station systems. The A&R applications range from the employment of an integrated test scheduling methodology to the use of knowledge-based expert systems to direct testing sequences themselves. It is obvious that an automated checkout and verification processor would do a better job of performing the highly repetitious functions involved in verification than a human ever could. The availability of an on-line computer-aided-design/computer-aided-engineering (CAD/CAE) data base on the Space Station - which would contain the details of the designs of systems and subsystems - could be utilized potentially by an expert system for the analysis of test anomalies as well as for determining test criteria to be used in the verification process. A great deal of technology development must precede the realization of such scenarios, but the payback potential of such capabilities is tremendous.

It should be pointed out that the application of A&R technology at the subsystem component level is very important in the verification process. The idea of built-in self-test can conceivably be extended from mere simple-minded hardware checkout exercises to intelligent director/monitor capabilities which have the ability to formulate test procedures and sequences as well as effect work-arounds in the event of anomalies. If a subsystem self-healing capability is to be employed on the Space Station, a self-diagnosis capability must be in place to initiate the process. Of course, self-healing implies automatic self-reverification, so the existence of a methodology to effect revalidation of self-healed systems at the component level must be the subject of A&R research. When the capability of self-diagnosis, repair, and verification are in place on the Space Station, it is logical to include with these functions a configuration management feature which would perform automatically and would post the actual system layout to an onboard CAD/CAE data base as appropriate.

While the notions of employing advanced technology for system checkout and verification are clearly beyond the state of the art today, planning for the eventual use of these ideas is essential. Therefore, for the Space Station IOC, system designs should incorporate "scars" such as (1) a variety of sensors which will allow for assessing the health and status of subsystem components, (2) data interfaces so subsystems can communicate with distributed processors, and (3) robust fault-diagnosis (self-test) equipment upon which evolving capability can expand.

While system checkout and verification of space flight vehicles are costly, time-consuming processes, their importance cannot be overstated. A program for automating the processes should be pursued from the standpoints of saving time and money as well as potentially increasing test applicability and accuracy.

CONSIDERATIONS FOR PLATFORMS

As noted in the Reference Configuration (NASA, 1984d), the platform concept has matured and evolved through several stages. In the earliest stages the concept of the unmanned Platform was based on a large structure whose components were copies of components to be used in the manned element. Two platforms were envisioned: one platform in polar orbit and one co-orbiting with the manned Space Station manned element. At the time that the reference configuration was finally completed, the Platform concept had become a relatively small design, and with the polar and co-orbit platforms very similar in basic configuration. To the greatest degree possible, the platforms are expected to use as many manned core elements as possible to help reduce cost. The platforms are assumed to be designed to be serviced on a 2-year cycle with a 1-year contingency. Thus, the platforms are similar to free-flying spacecraft in that they must be very much automatic in their operation, although because they carry experiments controlled from the ground, the automated features do not create an autonomous spacecraft.

NASA has emphasized design for on-orbit repairability in spacecraft for some time, anticipating the utilization of capabilities made possible by the Shuttle's becoming operational. Recent experience in the retrieval and repair of the Solar Maximum Explorer (SME) has demonstrated the effectiveness of this design approach.

Consequently, automation and robotics on the platforms will benefit from techniques already developed, applied, and planned within NASA. The Platforms will have aspects of free-flying, repairable, serviceable spacecraft on the one hand and aspects of the evolvable Space Station core on the other. Moreover, the Platforms are anticipated to carry many instruments which, themselves, have repairability and resupply capability built in. Much automation on the platforms will, thus, be the responsibility of the payload designer and will not have a direct impact on Space Station automation and robotics. Instrument control, data handling, data preprocessing, data preparation, command decoding, fine pointing, ground interaction, and so forth will be handled within each experiment (with certain restrictions). Certain interactions will be constrained, such as instrument failure management, to meet typical spacecraft bus requirements.

Servicing will benefit greatly from robotic applications for the platforms. Plans call for STS and OMV servicing of the Polar Platform while the co-orbiting Platform may be serviced from the STS or OMV, or by rendezvous with the Space Station itself. Since the major part of servicing for the Platforms is instrument modules for instruments themselves and orbital replaceable units for engineering servicing, the utilization of advanced sensory capabilities in the remote manipulator system and on the OMV may be considered to improve work efficiency. Improved work efficiency would be most beneficial in the case of on-site servicing by the STS with its limited on-orbit time.

For the co-orbiting platform more options exist, since this platform can be brought into the proximity operational zone or docked to the Station. In the latter case the capabilities developed for the Station (and addressed earlier in this section) could be utilized to perform servicing.

One additional aspect of servicing in the remote modes (via OMV) is the need to provide communication and particularly the vision aspect of teleoperation or telepresence.

Communication to and from the Space Station could, during proper orbital planning, be via radio-frequency or laser communication link to avoid TDRS/TDAS link time delays. In addition, heads-up displays could be considered with integrated information display to facilitate the teleoperation function. If practical means can be incorporated to give three-dimensional display and computer-generated perspective views from stored platform image data, the astronaut performance might be enhanced in the servicing operation.

Communication itself has other aspects which might benefit from automation. Expectations of data rates and volume from the Platform instruments are in the range of 10^8 bits per second and total data 10^{11} bits per operational event, respectively. Certainly, saturation of TDRS/TDAS is a possibility when the entire Space Station Constellation data rate and volume are taken into account. A dynamic scheduler and communications controller for the Space Station Constellation (Manned Core and two Platforms) might be required to properly allocate communications channels and times to avoid conflict. Humans are not capable of handling this task, since orbit phasing shifts constantly and since communication must be dynamically managed over orbit-to-orbit time intervals.

CONSIDERATIONS FOR SPACE STATION OPERATIONS

The applications of automation and robotics technologies to Space Station operations are presented in two parts. The first topic to be addressed is the application of A&R technologies to functions which should result in decreased operations requirements. Next to be presented is a discussion of the applications of A&R technologies to operations and procedures to mechanize some of those functions.

The identification of appropriate roles for man and machine is extremely important from the standpoint of developing a sound, cost-effective IOC and growth station design. It can be very costly to pursue an arbitrary technology development plan without having first defined the proper functions to automate related design cost impacts and R&D risk.

For purposes of assessing crew productivity impacts, two factors must be evaluated: (1) detailed component failure frequencies and (2) time required to resolve each type of failure. The product of these two variables yields "hours/mission cycle." If this product can be estimated for various classes or groups of components (e.g., batteries, fuel cells, solar arrays, etc.), assessment of man/machine alternatives for a given subsystem can be placed on a more rational basis.

Skylab docking experience indicates that roughly 8 to 10 hours was required for the complete docking process. However, the Shuttle Operations group has suggested using 4 to 7 hours because of improvements in technology and crew training. The key productivity aspect of the docking process is the fact that during docking maneuvers at least two individuals are generally monitoring and performing command and control functions for the full 4 to 7 hours. Although not a productivity problem under present Shuttle operations, the planned biweekly Shuttle and orbital maneuvering/orbital transport rendezvous and docking could consume a sizable amount of time using present procedures (Langley, 1984). Structural manufacturing (stress situations) and system assembly will have the greatest impact on station crew productivity and safety during the period around IOC, when assembly activities are highest. During this period, considerable EVA and ground support will be required. In conjunction with the assembly function, a sizable amount of mission planning will also be required by the ground crew, with a gradual shift to the station crew in later years.

The Space Station RFP (NASA, 1984e) system level requirements delineate crew productivity (as related to mission completion) and safety as key design considerations.

Table 2, based on Skylab and Shuttle experience, clearly shows that the individual productive time available is on the order of 10 hours per mission day. This productive time must include subsystem operation, monitoring, calibration and fault diagnosis/correction, operations planning, EVA, rendezvous/docking, and miscellaneous housekeeping as well as experimentation, observation, manufacturing, and other user-related work. Clearly, it will be advantageous, if not essential, to automate many of these tasks.

TABLE 2.- APPROXIMATE ON-ORBIT TIME AVAILABLE FOR COMMAND/CONTROL TYPE FUNCTIONS (HR/PERSON/DAY)

Housekeeping Functions	Hr/Person/Day
Presleep Activities	0.7
Sleep	8.0
Postsleep Activities	.7
Meal Preparation	.3
Meals	1.0
Postmeal Cleanup/Biocide Application	.3
Waste Water Dump	.3
Supply Water Dump	.3
CO_2 Absorber Replacement	.3
Fuel Cell Purge	.2
Check Safety Devices	.6
Crew Free Time	1.0
Subtotal	13.7
Productive Time Available	24 - 13.7 = 10.3

As an example, consider the monitoring and verification activities associated with command and control tasks. Presently, the monitoring function is done primarily via ground control. Loftus (1983) reports that roughly 70 percent of the monitoring points are automatically telemetered to ground control. The remaining 30 percent, or approximately 1000 data elements, are monitored by the crew onboard. Using a standard scan rate of 1 second per data element (as confirmed by Shuttle experience) and monitoring twice a day per standard procedures, a total time of 0.6 hour per day results (Freeman, 1980). If the monitoring function were to be completely autonomous from the ground, existing procedures would require an additional hour per day to complete the monitoring function.

The verification and calibration function is generally more complicated because it usually requires more than one instrument reading, a comparison of data from either ground control or other instruments onboard, and, possibly, a spacecraft control decision followed by a system command and followup verification. Both Skylab and Shuttle operational histories suggest that verification and calibration functions require on the order of 0.3 crew hours per function per day. Table 3 provides an extrapolated baseline list and estimated times of Space Station verification and calibration tasks based on present verification or calibration experience and the previous conceptual design.

TABLE 3.- POTENTIAL SPACE STATION VERIFICATION/CALIBRATION FUNCTIONS

Functions/Tasks	Approx. Time (Hr/Day)
Plan Mission	0.5
Verify/Calibrate	
• Inertial Unit	.3 (Done Twice/Day)
• Docking system	.3
• Accelerometers at Structural Extremities and GNC, e.g., Global Positioning System (GPS)	.3
• Thermal Control Systems	.3
• Structural and Mechanical Loads	.3
• Station, Experiment and Platform Pointing or Relative Alignment	.3
• Power Subsystems	.1
• ECLS Subsystems	.1
• Experiment Instrumentation	.6
• Test Instrumentation Onboard	No Value
Parameter Updates and Data Storage in Preparation for Next Verification/Calibration Exercise	.1
Total Approximate Daily Time:	3.0 (4)

Verification and calibration functions may require that a command and control decision be made, followed by a change in state of a given subsystem or the station as a whole (e.g., change in station attitude to allow for platform accommodation). The command and control function initiated by the station or ground crew is generally a semiautomated function requiring minimal crew interface (i.e., initiation of control sequences by switch activation). Therefore, it appears that the major tax on the crew lies with (1) the monitoring and verification functions which provide the inputs used in making command and control decisions and (2) making the proper decisions and initiating the appropriate followup control sequence.

System anomalies and failures require both troubleshooting and decisions concerning corrective actions. Both Skylab and Shuttle operational logs indicate that the resolution interval can vary from 5 minutes to hours, and in some cases days; one example is the problem with the Skylab Control Moment Gyro (CMG). In some cases a failure is never resolved. The erratic behavior of the Skylab CMG's is an excellent example of an unresolved failure which had a major impact on crew productive time and safety. Overall, Skylab experienced a system anomaly or failure on the average of once every two mission days.

The Space Shuttle failure history analysis has not been completed to date. Therefore, only summary information is provided here. Overall, the more recent missions have seen a major reduction in failures from an average of six anomalies or failures per mission day to four. The Shuttle Quality Assurance Office reported that over the 13-flight span, literally all avionics and instruments have failed at one time or another; major structural and mechanical failures have included thermal protection, brakes, and landing gear; software problems have generally involved initiation format errors caused by not reformatting all other linked programs when a reprogramming change was incorporated; electromechanical failures have involved TV cameras, recorders, printers, actuators and door mechanisms; fluid problems have included leaks in coolant system along with valve, pump, and fuel cell failures; finally, electrical problems have typically been with heaters, thermostats, wiring, circuit breakers, and switches.

Besides troubleshooting and repair activities associated with the station itself, the onboard and external experiments or manufacturing will also require periodic servicing. Skylab experienced a small number of "unscheduled" experiment problems. As a start toward understanding the minimum servicing requirements for experiment or manufacturing processes, consideration should be given to periodic planned maintenance for several of the experiments. The major concern here is the potential frequency at which EVA may have to be employed to service the external station experiments and the platforms.

The combination of the anomaly/failure frequency and the drain on crew productive time asserts troubleshooting and maintenance as critical functions.

Accepted human engineering standards suggest that the following key criteria be used for determining when to automate functions (Van Cott and Kinkade, 1972; Von Tiesenhausen, 1982):

(1) Automate to avoid perceptual saturation.

(2) Automate to reduce concurrent tasks.

(3) Automate tasks on compressed timelines.

(4) Automate to avoid human bandwidth limitations.

(5) Automate routine tasks.

(6) Automate memorization tasks.

(7) Automate sequential and time tasks.

(8) Automate monitoring tasks.

(9) Automate time consuming, boring, or unmotivating tasks.

(10) Automate emergency-prevention devices.

(11) Automate complex mathematical or logical tasks.

(12) Automate complex tasks that must be performed rapidly.

(13) Automate to enhance system reliability.

(14) Automate safety endangering tasks.

(15) Automate systems with consideration to crew acceptance.

The crew acceptance element is extremely important, as will become apparent in the following discussion.

The network analysis indicated subsystem checkout and fault repair as major man/machine interfaces. Consideration will be given to the fault repair function first. Existing Skylab and Shuttle failure histories indicate that power anomalies and failures occur on the order of one every 17 (Skylab experience) and 2 (Shuttle experience) mission days, respectively. Even though anomalies may not result in actual component failures, they still require frequent monitoring and troubleshooting time intervals, which detract from the valuable 10-hour customer productivity envelope and therefore assert maintenance as a critical function. Skylab and Shuttle operation logs report a fairly wide range of time for correcting anomalies and failures, ranging from 5 minutes to hours. EVA has been suggested for maintenance of power components external to the pressurized modules. Although state-of-the-art, EVA is extremely time consuming (3 to 4 hours is generally required for prepreparation planning activities, donning and checking out the equipment, and depreparation activities). Additionally, EVA does have several hazards associated with it (e.g., variable pressure environments, potential suit punctures, uncontrolled decoupling from the spacecraft, etc.). Out of the above list of criteria, items 3, 9, 11 and 14 directly apply. Item 3 applies because EVA is a time limited activity. Item 11 is germane because troubleshooting anomalies, or faults, can be a very complex process of elimination. Item 9 applies because EVA is time consuming. Item 14 of course applies because of the EVA-associated hazards. The key thrust here is that EVA is not eliminated but reduced in frequency. Therefore, it appears that fault management is a good automation candidate. As a spinoff, if fault management were automated then it appears that the subsystem assembly and checkout functions might be simplified for either on-orbit or ground crews.

Similarly, the mission monitoring, verification, fault management and docking activities controlled from the command and control modules can be evaluated. Table 3 suggested that monitoring, verification, and calibration functions could consume about 4 to 5 hours per mission day, or roughly 40 to 50 percent of the 10 hours available productive time. Information received from the Shuttle operations planning group suggests that, with the exeception of experiments, monitoring, verification, and calibration functions are considered repetitive and time consuming by the crew and are therefore good candidates for automation. Additionally, verification tasks can run in parallel and therefore pose a sizable problem in information sorting and assimilation. By automating both monitoring and verification and calibration tasks, the system would be in direct consonance with items 1, 2, 4, 5, 6, 7, 8, 9, 11, and, in particular, item 15, the crew acceptance element. In the case of experiments, the sheer quantity may make the verification and calibration functions unmanageable without the help of automated monitoring and calibration devices.

However, care must be taken when assessing automation concepts for this area because of

- The potentially large number of nonroutine tasks (which may make the function difficult and costly to automate)
- The potential interface problems associated with having to monitor, collect, and compare a vast array of different experimental variables and data formats
- The constantly changing variety of experiments

The mission planning and maneuvering tasks present interesting outcomes when measured against the automation criteria. Mission planning and maneuver initiation tasks are at opposite ends of the time spectrum. Mission planning requires much more time than activating a switch for a maneuvering command. The planning task requires consideration of many different control variables, tradeoffs, and time windows. In accordance with items 1, 2, 3, 4, 11, and crew acceptance 15, this task is a reasonable candidate for automation. Similarly, although the time required to initiate a maneuver is small, consideration of numerous control variables and time windows makes planning and maneuvering very similar. Nevertheless, the astronauts voiced concern over arbitrarily giving up manual control. Tasks such as reboost or maneuvering for thermal control are considered too critical for the crew to relinquish. Clearly, this is an area that requires further definition. Along these lines, the results of the docking tasks are equally interesting.

Discussions with the Shuttle Operations Group indicate that the final fine alignment and actual docking functions are two tasks the crew particularly prefers to control. The several hours of rendezvous monitoring fit nicely under items 5, 6, 7, 8, and 9 of the automation criteria.

In summary, it appears that monitoring, verification and calibration, fault isolation and management, station assembly, EVA, mission planning, rendezvous, and limited aspects of station state changes are reasonable automation candidates.

Analysis should be performed at a level of detail sufficient for each of the automation candidates to be associated with the various Space Station subsystems. As an overview, Table 4 relates each candidate automation function with its applicable subsystem in the overall Space Station System hierarchy. This table indicates which functions appear reasonable to automate within each subsystem. For example, automation of potential EVA's (such as module changeout or in-place maintenance) is associated with power, propulsion, thermal control (radiators), structures, and external payloads because these subsystems are largely external to the pressurized areas of the station. Similarly, automation of the mission planning function is associated primarily with communication and tracking, data handling, crew systems, and payloads (i.e., sequencing assembly and initiating experiments). In developing the foundation for a system autonomy and automation plan, it is essential to understand the overall function allocations by subsystem. Table 4 provides this top-level system view.

TABLE 4.- RELATIONSHIP OF AUTOMATION FUNCTIONS TO SUBSYSTEMS

Space Station Subsystems	Automation Candidates						
	Monitoring	Verification/Calibration	Fault Isolation/Management	EVA	Mission Planning	Rendezvous/Docking	Subsystem State Change
Power	X	X	X	X*	X*		X*
Guidance, Navigation, and Control	X	X	X			X	X
Communication and Tracking	X	X	X		X	X	X
Data Handling	X	X	X		X	X	X
Propulsion	X	X	X	X		X	X
ECLS	X	X	X				X
Thermal	X	X	X	X			X
Structures/Mechanisms	X	X	X	X*	X*		X
Crew Systems		X	X		X		X
Payloads	X	X	X	X*	X*	X	X

*Mission planning and EVA functions apply to both station assembly and servicing.

The potential for the application of A&R technology to Space Station operations is most promising. Planning and the scheduling of the highly repetitive functions involved with operations are key candidates for automation. The Mission Planning and Analysis Division at JSC has demonstrated a prototype of a knowledge-based system named NAVEX for assuming some of the role of the ground navigation console function for Shuttle missions. The Artificial Intelligence Office at JSC has developed a prototype demonstration expert system for ground operations support of the Shuttle pressure control system to demonstrate applications of automation to most of the operation of a complex system. The adaptation of knowledge-based expert systems for performing flight operations tasks like consumables budgets, electrical power management, and other labor-intensive ground monitoring functions - especially those involving trend analysis - is limited only by the state of the art of today's technology. Research in A&R technologies should bring maturity and utility to these tools and make automated operations a reality.

CONSIDERATIONS FOR CUSTOMER PAYLOADS AND EXPERIMENTS

Customer payloads and experiments are by their nature relatively independent, self-contained flight packages which will probably rely on the Space Station only for such services as power, thermal control, scheduled data dumps, command interface, and gross pointing. While it is the responsibility of the individual customers involved to incorporate automation and robotic technologies into their flight packages, it is obvious that the more automation utilized, especially for failure recovery, the better the chances for successful project and experiment completion. Based on today's technology, it is difficult to automate research, but ancillary research activities such as data collection and experiment monitoring are functions which are well suited to be automated. Processes which require precision, timeliness, repetition, and/or sequencing must be at least partially automated in order to be effective. The application of advanced A&R technology to these functions to maintain production continuity has been pointed out by General Electric (1984). The application of A&R technology to customer payloads and experiments will also enhance the fall-back position of packages which experience on-orbit repairable failures. Since crew intervention and support will be a very limited resource (especially considering timeliness of repair to meet critical-event windows), the chances of a successful experiment and payload flight could certainly be enhanced by the existence of an automated self-repair feature. A knowledge-based expert system could also be a tremendous boon to payloads and experiments. The incorporation of sensors throughout flight packages would allow an expert system the capability to ascertain status at the component level and to formulate corrective action predicated on sensed trends before hard failures could occur. An expert system could also provide conflict avoidance and resolution for payloads and experiments having time-critical windows and/or targets of opportunity. In short, expert systems are very promising for the enhancement of payload and experiment flight success. Appropriate "scarring" at IOC for growth may require provisions for the necessary sensors to support the eventual applications of expert systems.

The utility of an automated space robot has tremendous implications for maintenance and refurbishment of customer payloads and experiments. One particular "scar" which has been identified for the IOC Station to allow for the eventual use of intelligent robots is to employ a design philosophy of making experiment and payload subsystems serviceable by teleoperated devices. The eventual assumption of service and maintenance tasks by an automated robot will be more easily effected if the tasks are initially designed for teleoperation.

Chapter 5

REPRESENTATIVE EXAMPLES OF AUTOMATION AND ROBOTICS APPLICATIONS

Several representative examples of specific applications of automation and automation techniques for Space Station systems and functions are presented below. While the list is not exhaustive, a number of specific applications are detailed to provide illustrations of potential applications for Space Station systems. It is important to realize that even with a high degree of automation available in some initial system designs, it is most certain that maturing technologies will be available for the growth Space Station. It is expected that the Space Station definition activities will identify additional functions which will be amenable to automation and robotics and that the most promising of these should be considered for incorporation in the A&R plans.

Five studies were performed as a part of the support provided to the Automation and Robotics Panel (ARP). These studies were designed to complement the broader view of the ARP by performing a vertical cut in specific functional areas. By focusing on specific Space Station activities, the objective was to identify major issues and applications. No attempt was made to establish a priority basis for selecting the specific Space Station activity singled out as the study subject. However, the areas selected were chosen to be important and illustrative. The topics for the funded studies were Autonomous Systems and Assembly, by Martin Marietta Corporation; Subsystems and Mission Ground Support, by Hughes Aircraft Company; Space Manufacturing, by General Electric; and Satellite Servicing, by TRW. The fifth study in this group, performed at no cost by the Boeing Aerospace Company, was the operator systems interface, which also includes an in-depth analysis of technology development forecasting for the specific area of operator-systems interface. Some of the results of these studies, as they bear on automation and robotics, are presented below. While in-depth, these studies are by no means exhaustive, nor even necessarily representative of actual elements of the Space Station Program. However, they do provide (1) specific results and recommendations in the areas under consideration, (2) illustrations of possible approaches to performing these types of functions, (3) sources of ideas to stimulate thought in other or similar areas, and (4) identification of specific or generic technologies that need further development.

AUTONOMOUS SYSTEMS AND ASSEMBLY OF LARGE STRUCTURES

Martin Marietta (1984) studied the use of autonomy and autonomous systems to implement Space Station functions, especially the assembly and modification aspects. The following key technology needs for A&R in the Space Station were identified (in the order of priority):

- Teleoperation (remote control)
- Proximity, touch, and force sensing
- Predictive displays
- Low-weight dextrous arm
- Dual arm coordination (figure 6)
- Advanced actuators
- Knowledge-based and expert systems
- Planners, both strategic and tactical
- Range and image understanding
- Special-purpose and multifingered end effectors for robots (figure 6)
- Multisystem coordination (figures 7, 8, and 9)

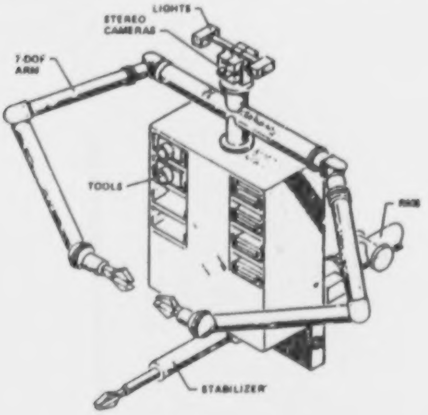


Figure 6.- Concept of telepresence and effector for the RMS (Martin Marietta, 1984).

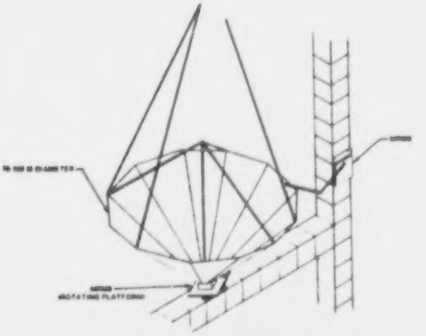


Figure 7.- Multisystem coordination concept for assembly of an advanced commercial communications system, a geostationary platform, at the Space Station (Martin Marietta, 1984).

In addition, the study identified general specific "hooks" and "scars" that need to be considered for an evolutionary Space Station, namely:

- Subsystems with fault-tolerant computers
- Accommodation of network growth potential
- Labeling, marking, or coding of modules
- Providing attachment points (handles and fixtures)
- Providing updatable knowledge bases
- Providing test points
- Modularizing subsystems

COMMUNICATION SUBSYSTEMS AND MISSION GROUND SUPPORT

Hughes Aircraft Company (1984) investigated three technology areas that potentially offer significant automation: (1) digital telephony, (2) automatic speech recognition and synthesis, and (3) data compression. Recommendations applicable to automation and robotics in the Space Station are as follow:

- Process user requests for communication services by an automated real-time system (figure 10)
- Perform automated short-term planning and scheduling of Space Station resources on the Station
- Implement a system for automated payload command screening
- Consider automatic speech recognition and synthesis as a basic mode of man/machine interaction for command and control during the design and development of the Station (figure 11)
- Design the data management system and other subsystems of the Space Station to accommodate fully automated fault diagnosis, isolation, and recovery within the monitoring function of the DMS.

The "scars" recommended to allow for growth and evolution of Space Station

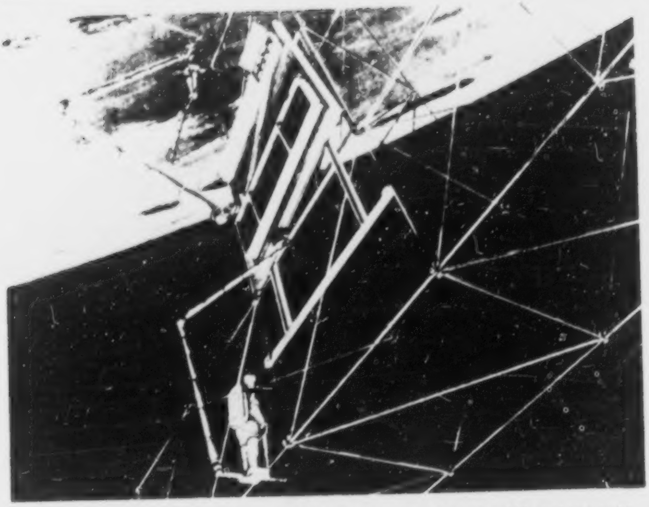


Figure 8.- Second generation MRMS artist concept with astronauts in EVA (Martin Marietta, 1984).

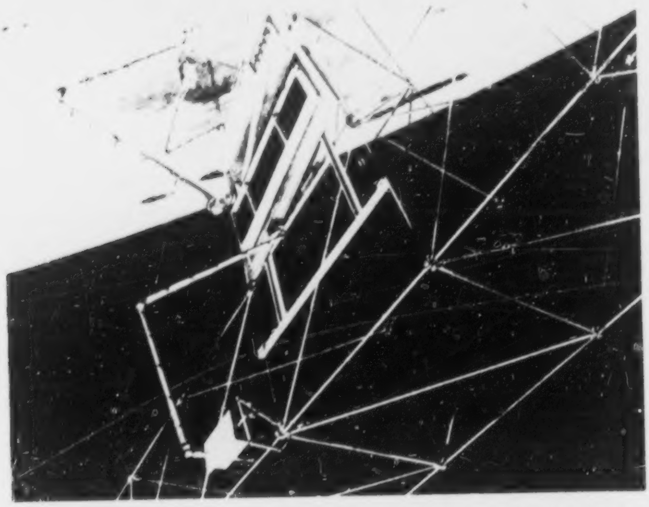


Figure 9.- Third generation MRMS artist concept with special end effectors replacing EVA astronauts (Martin Marietta, 1984).

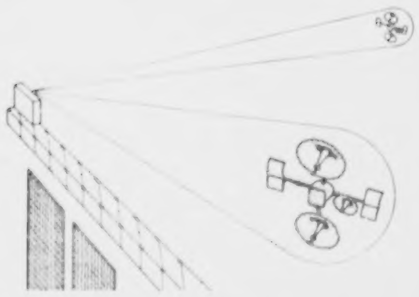


Figure 10.- Concept using multibeam phased array for communications with co-orbiting platform (Hughes Aircraft Company, 1984).

communications control are in the following areas:

- Resource scheduling - allows growth toward real-time expert system

- Command constraint checking - allows growth toward a real-time rule-based expert system

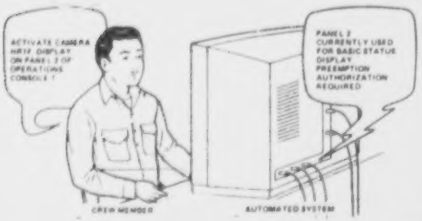

ACTIVATE CAMERA DISPLAY ON PANEL 2 OF OPERATIONS CONSOLE 1
PANEL 2 CURRENTLY USED FOR BASIC STATUS DISPLAY PREEMPTION AUTHORIZATION REQUIRED
CREW MEMBER
AUTOMATED SYSTEM

Figure 11.- Illustration of automated speech recognition and synthesis (Hughes Aircraft Company, 1984).

SPACE MANUFACTURING CONCEPTS

General Electric (1984) assessed over one hundred potential Space Station experiment and manufacturing concepts and selected two manufacturing design concepts for in-depth development of automation requirements.

- Gallium arsenide electroepitaxial crystal production and wafer manufacturing facility (figure 12)

- GaAs VLSI microelectronics chip processing facility (figure 13)

The two processes should evolve toward full automation in maintenance, repair, and refurbishment (figure 14). One unique aspect of a space manufacturing facility compared to a terrestrial factory includes the inability to bring technicians and specialists in for maintenance and malfunction repair. Therefore, the advanced automation technology requirements identified by the study are those systems required to remotely monitor and diagnose and to automatically reconfigure, maintain, and repair in the event of malfunction. These requirements embrace a broad spectrum of enabling technologies ranging from ultimate expert systems which monitor, diagnose, and reconfigure to teleoperators and robotic manipulative systems that perform manufacturing, servicing, and repair functions under supervisory control from either the Space Station or the ground.

SATELLITE SERVICING

Among the significant results concerning automation and robotics issues related to satellite servicing (TRW, 1984) has been the estimated 40- to 60-percent savings in crew time for four representative, but diverse, servicing scenarios. These scenarios are outlined in figures 15 through 18. Each figure shows a sketch of the mission concept and lists scenario highlights and key automation requirements. Also shown are estimated hours of crew activity required, with and without automated servicing support.

In addition, TRW identified 12 key automation technologies used in servicing and assessed both the current and projected technology statuses as well as the priorities of these technologies. Table 5 summarizes these results.

Growth was also addressed in the TRW report under the assumption that servicing functions would be required to expand as

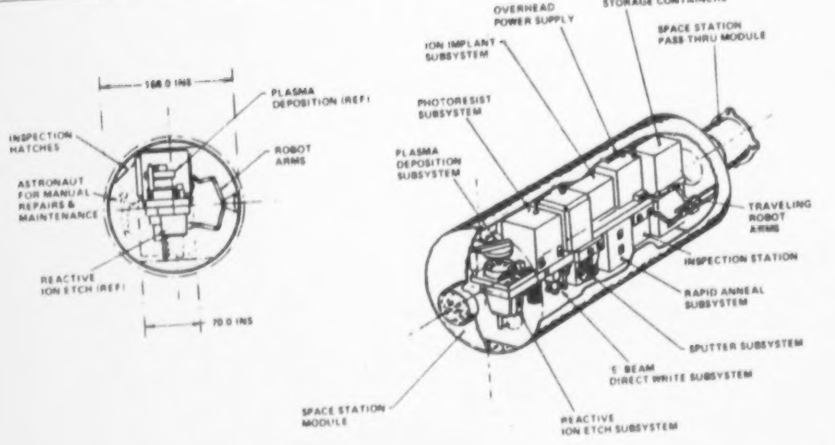

168.0 INS
PLASMA DEPOSITION (REF)
INSPECTION HATCHES
ROBOT ARMS
ASTRONAUT FOR MANUAL REPAIRS & MAINTENANCE
REACTIVE ION ETCH (REF)
70.0 INS
WAFER & SUPPLY STORAGE CONTAINERS
OVERHEAD POWER SUPPLY
SPACE STATION PASS THRU MODULE
ION IMPLANT SUBSYSTEM
PHOTORESIST SUBSYSTEM
PLASMA DEPOSITION SUBSYSTEM
TRAVELING ROBOT ARMS
INSPECTION STATION
RAPID ANNEAL SUBSYSTEM
SPUTTER SUBSYSTEM
'E' BEAM DIRECT WRITE SUBSYSTEM
SPACE STATION MODULE
REACTIVE ION ETCH SUBSYSTEM

Figure 12.- Automated gallium arsenide microelectronics chip processing facility concept (General Electric, 1984).

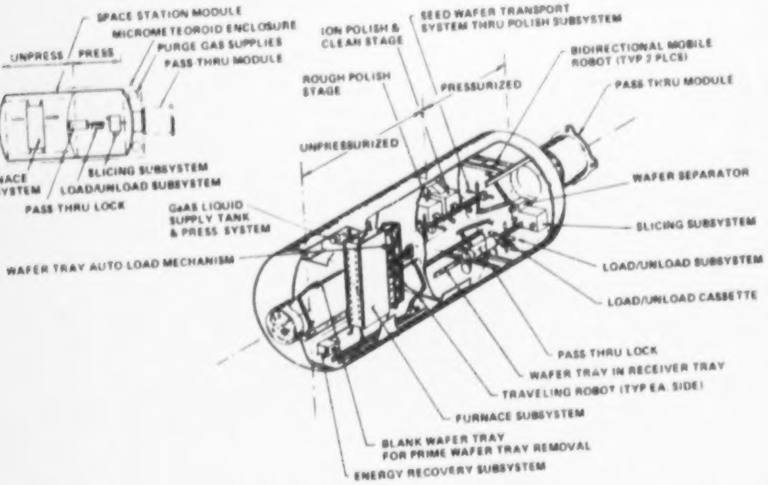

SPACE STATION MODULE
MICROMETEOROID ENCLOSURE
UNPRESS
PRESS
PURGE GAS SUPPLIES
PASS THRU MODULE
FURNACE SUBSYSTEM
SLICING SUBSYSTEM
LOAD/UNLOAD SUBSYSTEM
PASS THRU LOCK
ION POLISH & CLEAN STAGE
SEED WAFER TRANSPORT SYSTEM THRU POLISH SUBSYSTEM
BIDIRECTIONAL MOBILE ROBOT (TYP 2 PLCS)
ROUGH POLISH STAGE
PRESSURIZED
PASS THRU MODULE
UNPRESSURIZED
WAFER SEPARATOR
GaAS LIQUID SUPPLY TANK & PRESS SYSTEM
SLICING SUBSYSTEM
WAFER TRAY AUTO LOAD MECHANISM
LOAD/UNLOAD SUBSYSTEM
LOAD/UNLOAD CASSETTE
PASS THRU LOCK
WAFER TRAY IN RECEIVER TRAY
TRAVELING ROBOT (TYP EA SIDE)
FURNACE SUBSYSTEM
BLANK WAFER TRAY FOR PRIME WAFER TRAY REMOVAL
ENERGY RECOVERY SUBSYSTEM

Figure 13.- Crystal production and wafer manufacturing facility concept (General Electric, 1984).

TABLE 5.- AUTOMATED SERVICING TECHNOLOGY ASSESSMENT

KEY TECHNOLOGY	STATE OF TECHNOLOGY			ENABLING TECHNOLOGY	ENHANCING TECHNOLOGY	PRIORITY RANKING
	NEAR TERM	INTERMEDIATE	LONGER TERM			
1 DEXTROUS MANIPULATORS, INC. SPECIAL END EFFECTORS	X			X		1
2 SERVICING/AUTONOMOUS SERVICING COMPATIBLE SATELLITES AND PAYLOAD UNITS	X			X		1
3 SPACE QUALIFIED ROBOTS, ROBOTIC SERVICING		X		X		1
4 DATA SYSTEM SERVICING SUPPORT	X				X	1
5 ADVANCED MAN/MACHINE INTERFACES		X			X	1
6 ADVANCED FLUID TRANSFER SYSTEMS		X		X		1
7 ROBOT VISION CONTROLLED SERVICING		X		X		1
8 AUTOMATED LOAD HANDLING AND TRANSFER			X		X	2
9 AUTOMATED RENDEZVOUS, BERTHING, AND PROXIMITY OPERATIONS		X			X	2
10 OMV WITH SMART FRONT END		X		X		2
11 KNOWLEDGE BASED SYSTEM SUPPORT (TROUBLE SHOOTING, PLANNING, CONTINGENCY RESPONSE)			X		X	3
12 REUSABLE OTV			X	X		3

servicing responds to demand. Seven advanced technology provisions have been suggested to facilitate the increasing capability:

- Advancement from teleoperation to robotic operation - an "intelligent" robot
- Refinement of teleoperators and manipulators - greater dexterity, more telesensing, touch sensors, and robot vision
- Increased use of machine intelligence - expert systems for diagnostics, troubleshooting, mission planning, logistics control, and other fields
- Increased data system support to the crew and automated operations
- Automatic traffic control, rendezvous/berthing control to meet greater traffic flow and to ensure safety
- Automated load handling and transfer, commensurate with increased traffic flow of equipment and supplies

To accommodate satellite servicing on the Space Station, TRW proposed a cylindrical hanger concept (figure 19) as a service bay. A dextrous manipulator for teleoperated or robotic application is used within the facility, having access to any part of the satellite being serviced by being attached to the RMS or a movable crew support arm.

Report conclusions from TRW (1984) are summarized in eight major points, as follows:

- Automation can make satellite servicing more productive, but accelerated development of automation hardware is needed.
- Servicing poses automation requirements significantly different from those of other Space Station orbital activities.
- Telepresence is the principal automation discipline required to handle task diversity and unforeseen situations.
- Teleoperation or fully automated (robotic) use of the same manipulators offers flexibility and adaptability.

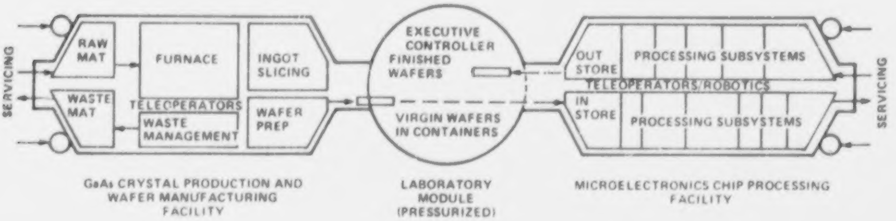
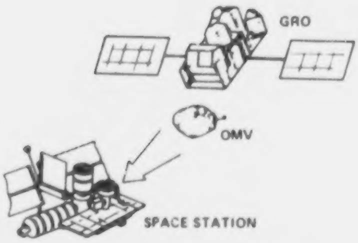

SERVICING
RAW MAT
FURNACE
INGOT SLICING
WASTE MAT
TELEOPERATORS
WASTE MANAGEMENT
WAFER PREP
EXECUTIVE CONTROLLER
FINISHED WAFERS
VIRGIN WAFERS IN CONTAINERS
OUT STORE
PROCESSING SUBSYSTEMS
TELEOPERATORS/ROBOTICS
IN STORE
PROCESSING SUBSYSTEMS
SERVICING
GaAs CRYSTAL PRODUCTION AND WAFER MANUFACTURING FACILITY
LABORATORY MODULE (PRESSURIZED)
MICROELECTRONICS CHIP PROCESSING FACILITY

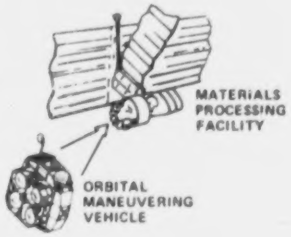
Figure 14.- Overview of the GaAs manufacturing facilities concept (General Electric, 1984).



1. SCENARIO HIGHLIGHTS
   - OMV RETRIEVES GRO FROM 400-KM ORBIT
   - RENDEZVOUS AND BERTHING AT SS
   - COMPREHENSIVE GRO STATUS TESTS
   - REPLACEMENT OF FAILED UNIT(S)
   - PROPELLANT REFILL
   - GRO CHECKOUT AND REDEPLOYMENT
2. AUTOMATION REQUIREMENTS
   - REMOTE CONTROL OF GRO RETRIEVAL
   - AUTOMATED RENDEZVOUS AND DOCKING AT SS
   - LOAD HANDLING AND TRANSFER BY TELEOPERATION
   - PROPELLANT REFILL
   - AUTOMATED TESTS, CHECKOUT, AND COUNTDOWN
   - DATA SYSTEM SUPPORT (DATA DISPLAY, DIAGNOSTICS, TROUBLESHOOTING)
3. CREW ACTIVITY COUNT

   ESTIMATED ELAPSED TIME:
   10.5 HR WITH AUTOMATION
   20.5 HR WITHOUT AUTOMATION

Figure 15.- Reference mission no. 1: Servicing GRO satellite on the Space Station (TRW, 1984).



1. SCENARIO HIGHLIGHTS
   - OMV ATTACHED TO SERVICING MODULE CARRYING FRESH SAMPLE MATERIAL
   - OMV TRANSFERS TO AND PERFORMS RENDEZVOUS AND BERTHING AT MPF
   - SERVICER EXCHANGES SAMPLE MAGAZINES AT MPS UNDER REMOTE CONTROL
   - OMV PERFORMS MPF ORBIT REBOOST
   - RETURNS TO SS; DELIVERS FINISHED SAMPLES
   - OMV REFURBISHED FOR NEXT USE
2. AUTOMATION REQUIREMENTS
   - LOAD HANDLING AND TRANSFER AT SS BY TELEOPERATION
   - RENDEZVOUS, DOCKING, AND BERTHING
   - SAMPLE MAGAZINE CHANGEOUT
   - MPF ORBIT REBOOST BY OMV
   - AUTOMATED CHECKOUT AND COUNTDOWN
3. CREW ACTIVITY COUNT

   ESTIMATED ELAPSED TIME:
   4.8 HR WITH AUTOMATION
   11.8 HR WITHOUT AUTOMATION

Figure 16.- Reference mission no. 2: Servicing free-flying materials processing facility (TRW, 1984).

1. SCENARIO HIGHLIGHTS
    - INSPECT PAYLOAD OR SUBSYSTEM TO BE SERVICED
    - CALL FOR AND RECEIVE REQUIRED PARTS OR SUPPLIES VIA ORBITER
    - TRANSFER SERVICING OBJECT TO AND FROM WORKSTATION
    - PERFORM REPAIR, REFURBISHMENT, AND MODULE REPLACEMENT
    - CHECK OUT AND RESTORE TO NORMAL OPERATION
2. AUTOMATION REQUIREMENTS
    - LOAD HANDLING AND TRANSFER
    - AUTOMATED TESTS, DIAGNOSTICS, AND CHECKOUT
    - MODULE REPLACEMENT BY TELEOPERATION
3. CREW ACTIVITY COUNT

    ESTIMATED ELAPSED TIME:
    2.9 HR WITH AUTOMATION
    6.5 HR WITHOUT AUTOMATION

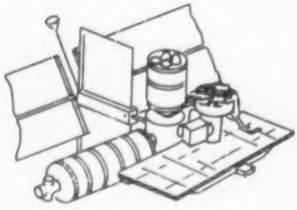
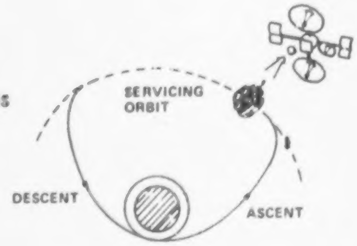


Figure 17.- Reference mission no. 3: Servicing of Station-attached payload or subsystem (TRW, 1984).

1. SCENARIO HIGHLIGHTS
    - CALL FOR AND RECEIVE NEEDED SUPPLIES VIA ORBITER
    - ATTACH SERVICING MODULE TO OTV
    - TRANSFER TO SYNCHRONOUS ORBIT; RENDEZVOUS AND DOCK WITH TARGET SATELLITE
    - CHECK OUT; REPLACE FAILED MODULE AND/OR REFUEL SATELLITE
    - RETURN TO SS (POSSIBLY BY AEROBRAKING MANEUVER
2. AUTOMATION REQUIREMENTS
    - LOAD HANDLING AND THRUSTER ON SS
    - ASSEMBLE SERVICING VEHICLE WITH OTV
    - AUTOMATED CHECKOUT AND COUNTDOWN
    - ORBIT TRANSFER, RENDEZVOUS, DOCKING, AND BERTHING
    - INSPECTION
    - MODULE REPLACEMENT
    - REFUELING



3. CREW ACTIVITY COUNT

    ESTIMATED ELAPSED TIME:
    11.1 TO 13.1 HR WITH AUTOMATION
    17.2 TO 19.2 HR WITHOUT AUTOMATION

Figure 18.- Reference mission no. 4: Servicing geostationary satellite in situ (TRW, 1984).

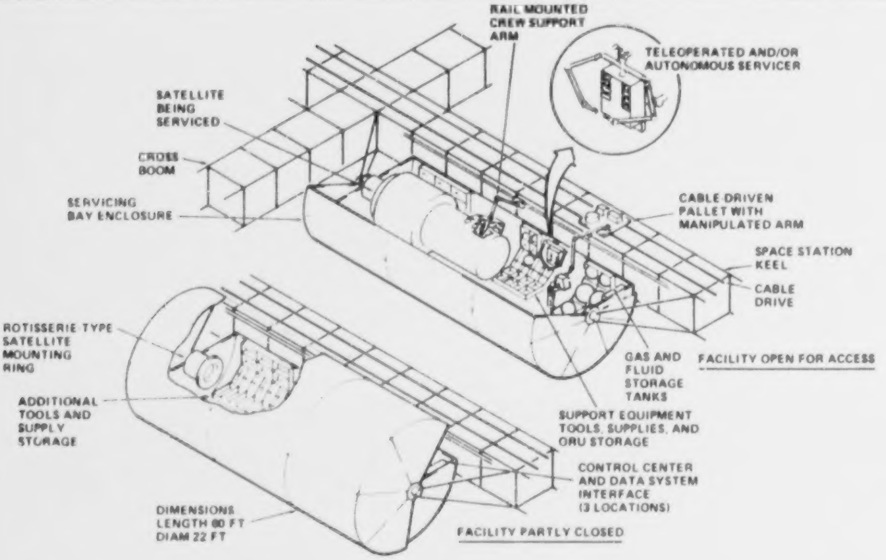

RAIL MOUNTED CREW SUPPORT ARM
TELEOPERATED AND/OR AUTONOMOUS SERVICER
SATELLITE BEING SERVICED
CROSS BOOM
SERVICING BAY ENCLOSURE
CABLE DRIVEN PALLET WITH MANIPULATED ARM
SPACE STATION KEEL
CABLE DRIVE
ROTISSERIE TYPE SATELLITE MOUNTING RING
GAS AND FLUID STORAGE TANKS
FACILITY OPEN FOR ACCESS
ADDITIONAL TOOLS AND SUPPLY STORAGE
SUPPORT EQUIPMENT TOOLS, SUPPLIES, AND ORU STORAGE
CONTROL CENTER AND DATA SYSTEM INTERFACE (3 LOCATIONS)
DIMENSIONS LENGTH 80 FT DIAM 22 FT
FACILITY PARTLY CLOSED

Figure 19.- Enclosed service bay concept (TRW, 1984).

- Major time delay in teleoperation on remote servicing missions can be avoided by scheduling operations for direct line-of-sight contact intervals.

- Geosynchronous satellite servicing demands more reliance on the full robotic mode, with remote human supervisory control and teleoperation being preferably performed from a ground station to avoid intermittency.

- Massive data system support is needed to plan, sequence, and execute tasks and to provide artificial intelligence support to the crew for troubleshooting, failure analysis, and in emergency situations.

- Major spinoff benefits to terrestrial applications will be in the area of flexible/adaptable automation for economical production of small quantities and in advanced data management and information transfer.

OPERATOR-SYSTEMS INTERFACE

Although not a part of the aerospace contractor study group that was contracted to investigate areas of automation and robotics application to the Space Station, Boeing Aerospace Company offered to assist the NASA effort by studying the impact of the Operator-Systems Interface (OSI). OSI is the system of hardware and software that facilitates communication between human operators and the hardware/software system which monitors and controls a functional system. On the Space Station, the functional systems that will be controlled and monitored will include those involved with housekeeping, stationkeeping, and mission and operations planning and scheduling.

The human factors aspects of OSI design lead to the following general requirements:

- The OSI shall be "user-friendly" and shall
  - Provide feedback to the operator

  - Provide appropriate level of detail
  - Allow different ways for operator interaction

- The OSI shall be multifunctional to minimize power, weight, and volume and to reduce operator workload and error rate.

- Information integration shall be used to reduce workload and error rate.

- Commonality in format and operation shall be maintained.

Space Station constraints on OSI design are given in figure 20.

- VARIETY OF MISSIONS AND MODULES REQUIRES VERSATILITY
- ZERO G ENVIRONMENT

  - POSTURAL CHANGES
  - LINE OF SIGHT FALLS 25 DEGREES BELOW HORIZONTAL REFERENCE
  - HEIGHT INCREASE
  - NORMAL OPERATING POSITION IS NOT SEATED
  - POSSIBLE CHANGES IN QUALITY OF VISION
- DIVERSE BACKGROUNDS OF CREW MEMBERS
- CREW MEMBERS NOT HIGHLY TRAINED IN ALL AREAS
- CREW MEMBERS ATTENTION MAY BE DIVIDED AMONG MULTIPLE TASKS

Figure 20.- Space Station aspects of OSI (Boeing, 1984).

The Boeing study concentrated on one aspect of OSI, an extravehicular (EV) robot. This was primarily selected because it represented a forward-looking application of automation and robotics technology. Some of the technologies required by a typical scenario of EV robot repair/replace tasks include

- Voice recognition
- Speech understanding
- Natural language understanding
- Machine reasoning
- Image understanding
- Adaptive data base management
- Expert systems
- Learning systems

Figure 21 depicts the Boeing robot design concept which is envisioned to be a free-flying vehicle that will operate outside the Space Station. The robot will be equipped with manipulator arms to hold itself to a work site and to perform physical tasks at a work site. The vehicle would be plugged into a specific berthing port on the outside of the station while being programmed and recharged with expendables. It would be deployed from that port and travel by its own propulsion system near the Space Station to perform its assigned tasks. The primary advantage of the EV robot system is that it would increase crew productivity by reducing the amount of time required for EVA on routine and frequently occurring tasks and by performing tasks that exceed human capability. It would also reduce risks to the crew by performing hazardous functions.

Boeing (1984) also conducted a technology assessment to examine the feasibility of an OSI that would support a fully autonomous EV robot system. They based their assessment on a 3-year, $12 million, international investigation called Transnational Assessment of Autonomous Robotic Generational and Evolutionary Technology (TAARGET). They concluded that it is technically feasible to develop an automated OSI by about 2010 to perform efficient supervisory management functions for an EV robot. The results of this study also show that it is technically feasible to develop an initial, fairly rudimentary EV robot and OSI system by about mid-1990 and a sophisticated, efficient, and convenient system by about 2010. The initial OSI system would have a limited supervisory capability and would be largely experimental in nature. The artificial intelligence technologies that will need to be pushed to develop OSI capabilities are

- Language representation
- Natural language understanding
- Analogical reasoning
- Nonmonotonic reasoning

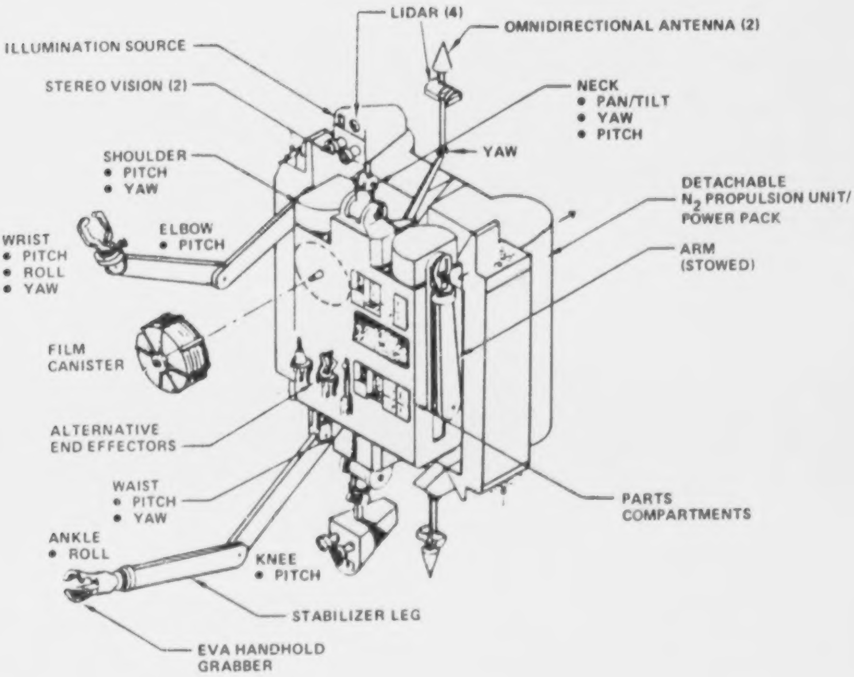
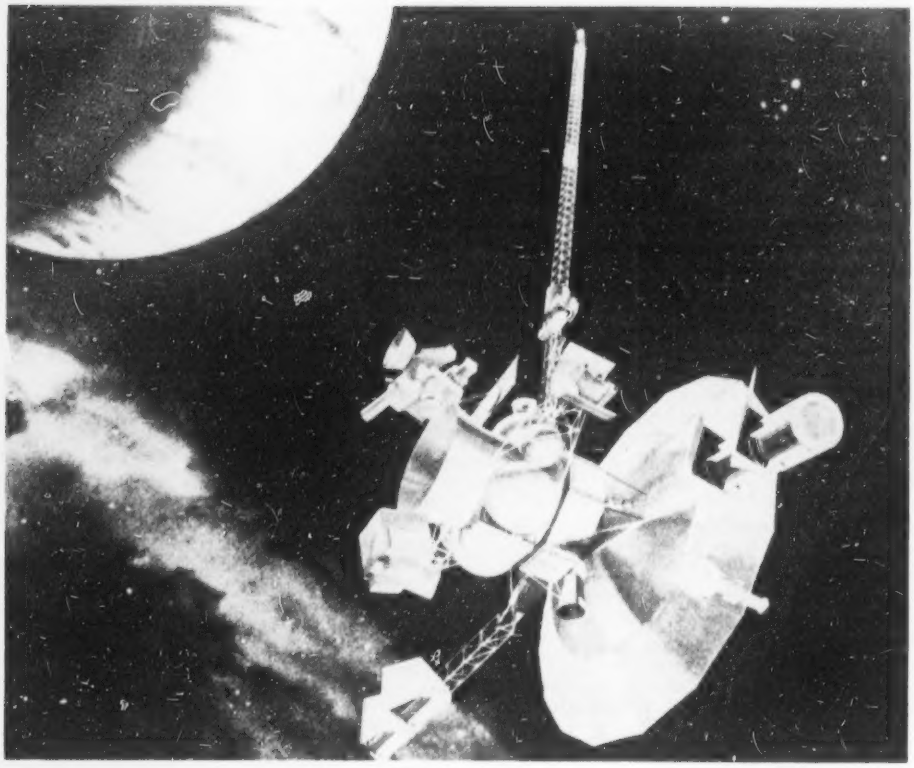

LIDAR (4)
OMNIDIRECTIONAL ANTENNA (2)
ILLUMINATION SOURCE
STEREO VISION (2)
NECK
• PAN/TILT
• YAW
• PITCH
YAW
SHOULDER
• PITCH
• YAW
DETACHABLE
N_2 PROPULSION UNIT/
POWER PACK
WRIST
• PITCH
• ROLL
• YAW
ELBOW
• PITCH
ARM
(STOWED)
FILM
CANISTER
ALTERNATIVE
END EFFECTORS
WAIST
• PITCH
• YAW
PARTS
COMPARTMENTS
ANKLE
• ROLL
KNEE
• PITCH
STABILIZER LEG
EVA HANDHOLD
GRABBER

Figure 21.- An external robot concept (Boeing, 1984).



Chapter 6

TECHNOLOGY BASE

In choosing a particular Space Station system or function as a candidate for automation, it is important to define what technology is required to automate that system or function and to assess the likelihood that that automation technology will be sufficiently developed within the time frame specified. To make an assessment of where a particular automation technology will be at some point in the future, it is necessary to define the present state of the art of that technology and then to project it, based on assumptions about the direction of research and progress likely in the interim. When automation of a system or function critical to the evolution of the Space Station cannot be sufficiently developed within the required time frame, then research must be initiated to push that technology. An effective infrastructure is essential to coordinate the incorporation of state-of-the-art technology and the advancement of the needed research to ensure continued advancements in Space Station automation.

The purpose of this chapter is to present major issues concerning the needed technology base relevant to Space Station automation. The chapter reflects these issues and is not intended as a comprehensive discussion of state-of-the-art automation technology. Furthermore, the issues presented here represent a conglomeration of information from many different sources. Much of the information came from a draft of an SRI International review of Automation Technology State-of-the-Art: Anticipated Technology Readiness (SRI International, 1985). Where possible, sources have been identified, but much of the information is presented anonymously. It is not the intention of this report to take credit for other people's ideas, but to present these ideas as an overview of the relevant issues concerning the automation technology base.

STATE OF THE ART

The current state of the art provides the base of automation technology. This base determines what automation can be incorporated into IOC systems now and which research efforts should be pushed to attain the automation goals of IOC and beyond.

Automation technology has been divided into twelve general categories. The present or near-term state of the art is described for each of these categories.

Teleoperation and Robotics

Teleoperation technology is concerned with manipulation and mobility devices whose sequences of actions are controlled by a human operator. Robotics extends the teleoperation technology by automating human manipulation capabilities. In the case of the robot, the sequence of operations is controlled by a computer program as opposed to direct human control. These technologies depend upon manipulator and effector design and control, robot programming, sensing and perception of the environment, and sensing of the robot's internal state.

Manipulator design and control. Manipulation technology consists of a well-developed body of kinematic theory for producing any desired movement of an end effector (e.g., a gripper or tool) carried at the end of a robot arm. The arm may be of any size and shape, but for complete control of end-effector motion it must have at least six independent joints. More joints are needed if the arm itself is also to get around obstacles. Recently, multiple small, three-jointed manipulators have been mounted on a hand to produce true fingers. In the near future we may expect to see the development of extremely small manipulators for confined spaces, and dendritic (multiply-branched) manipulators for complex manufacturing and assembly tasks. We also expect to see interchangeable effective tools for complex servicing and assembly tasks. We are a long way from having the human operator indicate an end result desired, and the effector carrying out the task with only minimal guidance from the operator.

"Fully general manipulation of an object thus requires that the manipulator have at least six controlled axes or degrees of freedom (DOF's). Typically, these are partitioned into three large-scale-motion axes to provide location and three wrist motions to provide orientation. Commercial robots are usually built with three locational DOF's, giving a total of four, five, or six DOF's. A servoed hand, or gripper - especially if its control is integrated with the arm controller - is often counted as another DOF.

"Very often, a robot does not need to be oriented to all parts of its environment, and relatively few degrees of freedom (DOF's) are required. For many forms of planar or pancake assembly tasks, robots with four DOF's are quite common. Systems with redundant (more than six) DOF's have been built, but the complexity of control and additional manufacturing costs have generally relegated such machines to research institutions, where control issues are studied. Implicit in determining the number of DOF's is the assumption that the robot, being fixed to a support, cannot move. However, the motion of a robot in a plane adds three DOF's to the system, or it can be used to reduce the DOF's in the arm itself. Mobile robots with vision and navigation capabilities have been the subject of much research.

"Links and joints are basically either prismatic or rotational. Three prismatic joints, mounted mutually orthogonally, form the Cartesian configuration. Replacing one prismatic joint (typically the x-axis) with a rotational one, often referred to as the wrist joint, gives the configuration known as a cylindrical robot. Replacing a second prismatic joint (z-axis) with a rotational joint, the shoulder, yields the spherical robot geometry. Finally, a third rotational joint that splits the y-axis into two fixed-length links forms a configuration known as an articulated, or elbow, robot. Robots are commercially available in these as well as other configurations.

"Once we know the robot's configuration and size, we can characterize geometric performance by three interrelated parameters: resolution, repeatability, and accuracy. Resolution, also called precision, is the smallest step size or increment of motion that a robot can perform. A minimum step size is mandated by the digital nature of the control system. Repeatability, or the ability of the robot to return to a previously specified point in space, measures the stability of the robot's internal coordinate system. Accuracy measures how well the robot can conform to an external coordinate system. Currently, repeatability is the most important parameter used in evaluating robots, because most robots move objects between known locations without these coordinates by being led through the sequence of activities it must perform.

"Repeatability performance, in turn, is governed by the quality of the components (encoders, bearings, servos, gears) used in the robot's construction.

"Repeatability is also a function of load and temperature changes. Resolution is primarily a function of the sensors used to measure link lengths or joint angles. The processor used to control the robot somewhat influences this parameter. The ratio of the robot's maximum reach divided by its resolution is often approximately 4000 and since $\log_2 4000$ *is approximately 12, 12-bit precision in arithmetic operations is needed. This can be readily maintained on 16-bit processors.*

"Accuracy is a function of the robot's geometric precision. When high accuracy is required, Cartesian robots seem to have advantages because there is (ideally) no interaction among the three locational DOF's. Robot accuracy becomes increasingly important whenever off-line non-adaptive programming techniques are used. Repeatabilities of 0.01 mm to 1 mm are typically quoted by robot manufacturers,

depending on the size and intended application of the robot.

"Current robots are basically high-precision electromechanical machines in which mechanical strength and precision geometric sensors are used to provide repeatability and precision. When comparing human and machine performance in this way, the desire is to match the overall ability and dexterity of human performance, not simply to match or exceed one or a small number of strength- or size-related parameters."

"Individual robot joints are moved by servo systems composed of an actuator, position sensor, and servo controller. The three classes of actuators in common use are hydraulic, electric, and pneumatic. Hydraulic drives are available in a number of sizes. Stepping motors, devices that rotate a fixed angular increment given a specified pulse sequence, are used in some robots. The stepping motor eliminates the need for encoders in certain applications because the angular rotation is simply the incremental step times the number of pulses. Problems in detecting overloads or stalls that decalibrate the robot make stepping motors alone suitable for only the least-demanding applications (Jarvis, 1984).

"The newest class of electric drives is the ac servo. The ac servo drives use switching electronics to generate wave-forms that allow ac motors to generate torque at low or zero rotational rates (Keebauch, 1984). Electric motors tend to have speed-torque characteristics not well matched to robot drive needs, so gearing, which generally provides a better match, is often used. Some direct drive motors (Motornetics, Inc.) are now being made that eliminate the need for gearing. High-energy, high-density, samarium-cobalt magnets provide dc motors with torque/weight ratios that may make direct-drive (the stator being connected to one link and the armature connected to the next) robot designs feasible. Direct-drive robots promise both speed and repeatability improvements over geared electric drive robots. Continued progress in developing improved magnetic materials (Robinson, 1984) suggests that motor performance will continue to improve.

"Pneumatic actuators, similar in concept to hydraulic drives, are also in use, offering some of the power-to-weight advantages but without the presence of hydraulic fluids. End effector or hand actuators are usually pneumatic, even on robots with otherwise fully electric drive.

"Designers of robots seem to agree more on position sensors, using predominantly incremental or absolute optical-shaft-angle encoders or resolvers.

"A robot's natural coordinate system is the set of joint angles and link lengths that define its position in space, called (not surprisingly) the joint coordinate system. A world coordinate system consists of the natural coordinates of the three orthogonal Cartesian axes and the three coordinates defining the orientation of the robot end effector. Mapping the robot's internal joint coordinates to the external world's coordinates is the problem of robot kinematics. There is generally no unique solution to this mapping problem. Specifying the preferred configuration is part of robot teaching or programming.

"A third robot coordinate system is the tool system. In this case, the origin and orientation of the coordinate system is aligned with the final link of the robot. This alignment allows natural specification of motion in the direction of the robot hand and in the plane normal to this direction.

"To ensure continuous and coordinated robot motion, we decompose the desired path into a series of short segments used to update the target position of each joint servo at rates of 20 to 100 times a second. For each time interval, we must compute the desired target values from the kinematic solution or an appropriate approximation. Acceleration and velocities are controlled by varying the distance increment between successive points. To allow the robot to move along specified paths, including straight lines, we transform world coordinates into the appropriate joint or link values. By matching the servo response times to the position update rate, we can ensure smooth and continuous motion.

"As an alternative to constraining all six robot DOF's by specifying coordinates, we can use a hybrid force and position mode. The result is called compliant motion. Two examples of the use of compliant motion are the driving of a screw and the turning of a crank. Force servoing is used to insert parts, assemble snap-together components, and follow surfaces (adaptive seam welding is an example of surface following). Obviously, force sensors normally supplement the position sensors normally employed" (Jarvis, 1984).

Robot programming. Robot control requires specifying tasks to be performed by the robot. Each task must be decomposed into a series of motions which, based on knowledge of the internal state of the robot and external state of its environment, will accomplish the desired outcome. To achieve movement, the robot's internal joint coordinates must be mapped to the external world's coordinates. The series of steps to achieve this mapping is accomplished through robot programming and teaching.

"Some features typically available in computer languages for programming robots include interaction with the teach pendant (a device that allows manual control of the robot motion), speed control of the robot, and a variety of constructs that define new robot coordinates in terms of previously taught or computed ones. Languages are normally executed by an interpreter instead of being compiled. The current situation with commercial robots is that each major manufacturer supports a proprietary programming language, with each differing in syntax but not significantly in semantics. Languages suitable for describing tasks naturally are still in the research stage.

"A general problem in robot programming is how to specify robot positions relative to the workplace. Normally, the robot programmer leads the robot through a set of positions using a teach pendant, generally switches or buttons that allow one joint to move or allow motion along one coordinate at a time. Some ability is provided to switch between coordinate systems, to specify speed, or to record locations. Joysticks or other techniques for indicating the coordinated motion of several DOF's simultaneously are seldom used" (Jarvis, 1984).

The current practice in the robot industry is hand coding of adaptive robot control programs by a person skilled in computer programming, robotics, and the particular procedure that the robot is to perform. Tedious efforts that must now be carried out by hand by the robot programmer include

- Constructing a syntactically correct program (several hundred lines to do a task such as remove a screw with a screwdriver)
- Naming dozens of coordinate reference frames and remembering how they are defined in terms of one another
- Measuring distances and angles on the object in order to establish nominal values for those frames in terms of Cartesian coordinates and Euler angles
- Coding data base access requests for the necessary CAD data

Semiautomatic generation of a program using information obtained by interacting with a person skilled in robotics is the subject of much research at present. Isolated parts of the problem seem to be solved, or to be close to a solution. Geometric reasoning, based in part on CAD data about individual part shapes, and automatic planning are important pacing technologies to develop an increasingly automated robot.

Lately, pursuit of semiautomatic program generation is causing a trend away from symbolic programming in a formal robot programming language towards "procedural" programming. In the former, the programmer tells the computer (in a formal programming language with a well-defined syntax and grammar) what the robots should do and how they should do it. In the latter, the programmer operates either simulated robots on a graphic display or the real ones to demonstrate to the computer what is to be done. By menu picks and other simple interactions, the operator helps the computer focus on the significant aspects of what he is doing with the real or simulated equipment.

For example, by moving an arm from one place to another, he might be pointing out a position for a workpiece, describing a tool trajectory, or defining a gripper orientation for grasping a particular object.

External sensors for robots. External sensors provide the robot with its sense of touch, sight, and hearing. (Computer vision will be dealt with in a separate section.)

"*Currently, component feeders and subassemblies are located with sufficient accuracy to allow insensate robots to perform the desired tasks. The additional expense required in this mode can easily exceed the initial cost of the robot. Also, much flexibility has been lost because of this special-purpose tooling. These limitations and the obvious costs of building highly precise robots are widely recognized and have sparked the development of sensor-based robots. Already, a few robots are commercially available with simple vision and tactile sensing*" (Jarvis, 1984).

Contact, or tactile, sensors may detect touch or measure pressure, force, or torque. These signals must be interpreted and integrated to indicate the nature of the environment to the robot so that the robot can carry out its goals. Contact sensing is one of the two ways that interactions between a robot and its environment can be monitored and controlled. These types of sensors are crucial to dextrous manipulation.

Recently, fingertip-sized sensors have become available that can measure pressure distributions over a planar region about one inch on a side. Such tactile arrays produce a two-dimensional image that can often be interpreted successfully with conventional visual image processing algorithms. Tactile arrays will be very useful in the future for handling small parts, and can be used to identify the parts as well as to determine accurately how the fingers are holding them. A variety of innovative transducers are used in tactile arrays, such as conductive elastomers and integrated circuits.

Tactile sensors either detect when the hand touches something, or measure some combination of force and torque components that the hand is exerting on an object. The term "tactile sensor" means the continuous variable sensing of forces in an array, as contrasted with simple touch, i.e., simple binary sensing at a single point. Tactile sensing implies skin-like properties, with which areas of force-sensitive surfaces are capable of reporting graded signals and parallel patterns of touching. The tactile sensor is used to communicate to the robot system the nature of the object being grasped. Information available from a tactile sensor could include resiliancy of the object being grasped, surface texture, surface normal, bounding outlines, surface curvature, and shape.

Additionally, tactile and force feedback can provide high precision, even in imprecise manipulators, by providing relative movement between the end effector of the robot and the object being moved. This feedback can also detect very small errors in the position of the manipulator by measuring the resultant forces, which can be very large. For example, manipulators with 1 mm open-loop resolution can perform 25 micron operations when under force control.

Although existing commercial tactile sensors are quite simple, having only a few touch elements, promising research is leading to commercial touch sensor devices within 5 years having the following specifications, (Harmon, 1982):

- 10 x 10 elements in 1 square inch
- Sensitivity of 1 gram with upper limit 1000 grams
- Low hysteresis, somewhat nonlinear
- Response time of 1 millisecond
- Robust skin

Until recently, an NxN sensor required NxN output leads to be sent to the processing and analysis device. Recent approaches use some form of multiplexing to decrease the number of wires. In Raibert's touch sensor (Raibert, 1982) each sensor element is provided with its own computer, and the processed signal is shifted across rows to obtain the output. Some interesting tactile sensors recently reported include

- Conductive rubber (Hillis, 1982)
- Tactile sensing computer (Raibert, 1982)

Range sensors are an important means of determining the location of objects with respect to the robot. In-air acoustic range sensors are accurate to about 1 millimeter over several meters. Laser range finders are accurate to about 1 meter over a kilometer; with a retroreflector on the target, however, they can easily measure to about a millimeter accuracy. A scanning laser ranger has been developed that simultaneously measures the reflectance of an object as well as its distance. This produces precisely registered range and intensity images.

The main drawback to current range finders is that they must be scanned slowly over a scene in order to determine the three-dimensional shape of the terrain and objects. The transverse resolution (beamwidth) of acoustic rangers and the range resolution of laser rangers is too coarse to be useful in many manipulation tasks.

Electro-optical devices that operate in picoseconds are now being developed. These will improve the resolution of laser rangers to the millimeter range without the need for a retroreflector on the target object. Four emerging technologies promise tremendous increases in speed of processing range data and images over present-day electronic silicon devices. These are gallium arsenide, all-optical transistors, Josephson junctions, and optical processors.

Internal sensors for robots. Internal sensors measure internal variables important to the control of a robotic mechanism, or provide information about the systems's well-being. The position and velocity of the joints in a manipulator or locomotion system are examples of critical internal variables used to control movements. Force, temperature, and pressure are often measured in order to assess the internal well being of the system. It is important to sense these variables, particularly for devices that must work for long periods without human intervention, or when no maintenance or repair is possible. Internal sensors are the easiest to implement since they have no direct interaction with the outside environment. One or another of these devices is found on every robotic mechanism.

Proprioception in robotics means sensing the posture of a mechanical manipulator, leg, or other jointed mechanism. This is used mainly in two ways - in controlling the mechanism whose posture is sensed, and in sensing the posture of a teleoperator master arm in order to command the motion of a slave arm.

Proprioception involves measuring the angle of each rotary joint and the extension of each telescoping joint in a mechanism. The joint position sensors are usually either potentiometers, resolvers, or encoders. Today, joint position sensors are accurate enough to enable a six-joint manipulator to place its hand anywhere within a 3-meter radius working volume with 1-millimeter accuracy. Highly accurate sensors for joint angles or extensions are delicate, expensive, and difficult to manufacture. They are also too large for use in miniaturized robots. In the future, it may prove easier to measure the position of the hand directly than to infer it from accurate measurements of each joint position.

Expert Systems

Expert or knowledge-based systems utilize information obtained from an expert about a particular domain to solve problems in that domain and perform at the level of the human expert. Although there is no definitive definition of an expert system, some of the features distinguishing them from standard application programs are

- Knowledge: They contain a data base of expert knowledge in a specialized area represented in a form that allows some sort of reasoning to be carried out. Most expert systems use a "rule-based" approach that represents knowledge in the form of modular facts and rules.

- Extensibility: The knowledge and the inference engine that makes deductions using this knowledge are kept separate, so that modifications in the rules do not affect the analysis process.

- An explanation system: Many systems can retrace the reasoning sequence used and explain what was done at each step and why. This explanatory capability enables the user to accept or reject the system's conclusions if he disagrees with its reasoning, and aids the expert in debugging the system.

- Incomplete or inexact data: Many of these systems can carry out reasoning processes on incomplete or inexact data.

"The current expert system technology consists of two basic ingredients: symbolic programming and knowledge engineering. Symbolic programming technology includes the fundamental science of symbolic computation, practical techniques for constructing symbolic programming systems, and techniques for building incremental programming environments. Knowledge engineering adds its own three key ingredients: problem-solving engines, knowledge bases, and aids for knowledge acquisition and knowledge-base maintenance" (Hayes-Roth, 1984).

At present, expert systems do not acquire their expertise through experience, but rather are given the needed information and the organization of this information by a knowledge engineer and an expert in the field. Recently the media has paid much attention to expert systems, often claiming these systems as a great cure-all for any problem. It is important to realize, in the face of this "overselling," that current commercial expert systems are effective only in narrow domains of knowledge.

An expert system can be considered as an idiot savant that can deal very effectively with a specialized field, but is incompetent to deal with topics not in this field.

The general categories of tasks that expert systems have been applied to can be broken down as follows:

- Interpretation/diagnosis: This category of expert systems includes those that can accept data from the user about a particular case and, when sufficient information has been received, return a diagnosis or interpretation. Examples of such expert systems include DENDRAL (Buchanan et al., 1978) and two medical expert systems, MYCIN (Shortliffe, 1976), and EXPERT (Weiss et al., 1981).

- Design systems: These are expert systems that may be given particular information and constraints and are required to produce an output that satisfies the given design criteria. An example is R1 (McDermott, 1981), an expert system that designs computer configurations.

- Prediction and induction systems: These systems accept data and look for patterns or other forms of order. When such patterns are found, they can be combined with information about a particular case to predict the most likely outcome. An example of an inductive system is INDUCE, which inferred the relationship between symptoms and disease in soybeans.

- Monitoring and control systems: These systems receive specific on-line data from the sensors on the object being monitored/controlled. These data are rapidly interpreted by the expert system and the appropriate responses generated. In a monitoring expert system, particular ill-defined situations are represented that will trigger specified alarms if they are ever detected. REACTOR, a nuclear reactor monitoring system, and VM (Fagan et al., 1979), a patient monitoring system for intensive care wards, are examples of this type of expert system. YES/MVS, an IBM system, is an example of a real-time expert system used to control an operating system. Often the generation of an appropriate response will require simulation of the expected effects of possible actions on the controlled system.

At present, each system must be developed for its intended application, requiring a significant investment of time and effort. However, tools that can speed the development process are beginning to become available. These tools range from such automated aids as token completion and spelling correction to line-of-reasoning traces, knowledge-base look-up, and system testing and validation facilities. The first knowledge-based systems have relied on shallow models, but research is underway to provide systems with deep models that are able to model the important interactions within a system. Natural language interfaces will increase the usefulness of knowledge-based systems in some applications.

"In the near future, we can anticipate an emphasis on (1) intelligent instruments that couple data collection with expert data interpretation, and (2) numerous high-value, specialized systems. Over time, these systems will lead to the construction of high-value knowledge bases. Initially, these knowledge bases will have a unitary, self-contained character. Each will employ its own conventions for knowledge representation and will address a specialized problem from one perspective.

"Within a few years, multifunction knowledge systems will emerge. That is, a single system will contain knowledge of benefit to many applications. As diverse bodies of knowledge cooperate to solve a single problem, more heterogeneous knowledge bases and general-purpose knowledge systems will develop. At the same time, these systems will join other technologies, producing integrated automation systems for manufacturing and other commercial activities.

"Both the technology and commercial applications should grow steadily and rapidly through the turn of the century. In the upward direction, user needs drive advances in knowledge systems technology and determine the economic and functional niches the technology will occupy. Specifically, knowledge systems address problems that arise from difficulties in retaining, transmitting, and applying know-how. Knowledge systems provide a means to employ know-how where it is needed, when it is needed, and at great speed. These are the qualities that attract those in factory automation, process control, safety systems, military intelligence, and weapons systems.

"In the downward direction, the field will expand in response to technology pushes. These include improved forms of conventional hardware and software for symbolic computing, less expensive memory and processors, standardized and increasingly reliable knowledge-engineering techniques, and possibly novel non-von Neumann architectures, such as those that the U.S. Defense Advanced Research Projects Agency's and Japan's fifth generation programs now pursue. However, no near-term breakthroughs are anticipated that will affect technology development. Rather, steady improvements in these directions should reduce cost, expand capability, and increase reliability, making an already practical technology much more so" (Hayes-Roth, 1984).

The present limitations of expert systems are of four types - (1) acquisition of knowledge, (2) basic limitations, due to an inability to represent certain situations (e.g., reasoning that deals with uncertain conclusions) or to carry out adequate reasoning processes, (3) "fragility" of the systems, i.e., their inability to deal with anything but their very narrow speciality, and (4) inability to know their limits, i.e., when not to advise.

The following limit the effectiveness of present-day expert systems:

- Knowledge representation: It is important to develop representations for particular domains that are computationally tractable and still capture the important characteristics of the domain, can accommodate qualitative reasoning, and can represent causal models.

- Knowledge acquisition facilities: There is a major problem in obtaining, representing, and debugging expert knowledge about a particular domain. Typically about 5 man-years of effort (using an experienced staff) are required to develop a large system that begins to be robust. Methods are currently being developed for dealing with these problems that should reduce the time it takes to build new systems; improving the knowledge acquisition ability of expert systems is a major thrust in the DARPA Strategic Computing Plan.

- Reasoning: A major concern of expert-system research is how to use uncertain rules (rules of thumb), so that degrees of belief in individual rules can be combined to obtain a final degree of belief. Since most human reasoning takes place on the basis of uncertain information and weakly supported implications, it is important that expert systems incorporate similar abilities.

- Explanation capabilities: The explanations are usually indications of the solution path traversed in order to achieve the present status, rather than being causal explanations of the type that people usually provide. However, what the user often desires is a causal explanation based on physical reasoning. This type of explanation usually requires that there be a model of the process being discussed. Recent research in medical expert systems uses such models for this purpose.

- Representing procedures: Automatic systems for fault isolation and diagnosis require reasoning about sequences of test and actions. Traditional expert systems, which encode most of their knowledge in the form of rules, are not well suited to representing such procedural knowledge.

- Lack of learning capability: The designer of the system, not the system itself, learns by experience as the system is used. Thus, the designer, not the system, modifies the rule data base. It is a nontrivial task to determine which rules need modification when the expert system is not performing up to expert standards. The designer must consult with the human experts to determine how the rules have to be modified or augmented. The system itself has no way of determining that the user is dissatisfied and no way of automatically correcting the source of the difficulty.

- Need for metaknowledge: The system should have knowledge about the knowledge that it contains - metaknowledge - and be able to use metaknowledge in its reasoning strategy. Such "higher-level" knowledge becomes crucial when large knowledge bases are to be used, since otherwise too much time is expended on unproductive searches and useless deductions.

Planning Systems

Planning will be an important and integral part of many of the functions carried out on the Space Station. Automatic planning has been studied using expert system concepts; however, it is an important area in its own right.

Planning, the determination of a pattern of actions that can be carried out to achieve a goal, can involve predictable actions and their effects (scheduling an astronaut's time) or less predictable situations (sending an autonomous robot to perform a complex task). The potential advantage of automatic over manual planning is that more complex and detailed plans can be generated more quickly and with fewer errors. Autonomous robotic devices require automatic planning to adapt to unpredictable or changing situations by replanning as the need arises. Automatic planning may be done either completely autonomously or interactively with a human supervisor.

Planning systems have not yet achieved the level of performance of the above expert systems. Although several research planning systems have been reported, they have not yet been used in an operational application. Automatic planning is an active subject of research in artificial intelligence (AI).

We encounter two types of planning problems in the Space Station.

- Planning under known conditions: Planning problems that begin with a set of well-defined initial conditions and utilize activities whose effects are known. The problem is to arrange the activities so that the best use of resources attains the best set of goals.

- Planning under uncertainty: Where the initial conditions may not be known beforehand, or the environment is not completely predictable, and it is therefore not possible to initially define the set of situations that will arise. Often only an initial set of "high-level" actions can be defined and the detailed actions are derived as the plan is put into action. Replanning as situations are encountered is often an important part of the process. This type of planning often arises in deciding how to move from one location to another, or in determining what actions are necessary to repair a failed component. One approach that has been used is to develop a hierarchy of plans, each serving as a skeleton for the problem solving process at the next level of detail, (Sacerdoti, 1977). In this way, complex problems can be reduced to a sequence of much shorter, simpler subproblems. One must provide a means, however, for plan modification, since portions of a plan expressed at a high level may turn out to be invalid when expanded on the detailed level.

Both types of planning have been investigated in an attempt to automate the planning process. An automatic planning system starts with a goal or set of goals, knowledge about the initial situation, facts about the world, and activities that can be carried out with an understanding of their effects on the world. The system will produce a plan or partial plan containing specific actions involving specific agents that will achieve the goals. Some planning research is directed toward developing methods for fully automatic planning, such as DEVISER (Vere, 1982), while other research is on interactive planning (e.g., SPOT, ATTENDING, and KNOBS), in which the decision making is shared by a combination of a person and a computer.

In order to develop a plan involving actions, it is necessary to represent the nature and the effect of the actions to the degree of detail required by the complexity of the planning situation. The representation issue lies at the heart of the automatic planning process. A good representation is one that captures the way the action changes the world and what conditions are necessary for that action to be applicable to a particular situation. It is also necessary to model the environment and, in more complex situations, the belief structures and goals of the agents carrying out the actions. Actions can be either deterministic or have some uncertainty concerning their effects. For deterministic actions, the representation must indicate the required conditions (before, during, and after) and the results or effects of that action. For probabilistic postconditions and nondeterminable operators the representation must indicate the probabilities of results that can occur. Because planning is a problem solving activity that involves exploration of alternative hypothesized combinations of actions, a symbolic model of the real world, referred to as a world model, is used to enable simple simulations of the situation to be run as the plans are evolved. As with all models, the world models used in problem solving are abstractions or oversimplifications of the world they model. If a CAD/CAM data base is available, it can be used as a source of descriptions of the world of the Space Station.

Man/Machine Interface

An important area of technology which will be necessary to enable and enhance automation functions onboard the Space Station is that of man/machine interface. Man/machine interface technology is a multidisciplinary area which includes the fields of electronic controls and displays, voice recognition and synthesis, computer graphics, instrumentation engineering, workstation design, and ergonomics. Because the field of voice recognition, synthesis, and natural language understanding is deemed to be critical to the automation function, it is covered in a separate section below.

The various man/machine interfaces within the Space Station will require integrated and consolidated electronic controls and displays to permit the effective human implementation, monitoring, and control of automation-intensive functions. The potential advantages of integrated electronic pictorial displays, generated using color computer graphics, are numerous. This type of display has proven to be a natural and powerful adjunct to automation in factories, medicine, computer aided design/computer aided manufacturing (CAD/CAM), even our most modern transport aircraft. Using integrated, pictorial displays, the human monitor/operator can be presented with information that can be assimilated much more rapidly and with better situational awareness than can be presented with arrays of electromechanical indicators - the method primarily utilized in the present Space Transportation System (STS). Using consolidated, multifunction controls, as opposed to large arrays of single-purpose controls - a method utilized primarily in the present STS - the human monitor/operator faces a cleaner, less cluttered control panel and one with a natural interface to automated sequences. Applied in conjunction with automation technology, electronic controls and displays have the potential to reduce training and cross-training requirements. This advantage would be provided through use of interactive tutorials in conjunction with knowledge-based systems. Thus, electronic control and display technology has the potential for working in conjunction with automation to provide safer and more efficient operations.

Integrated electronic controls and displays as a means of implementing the man/machine interface have potential for contributing to automation efficiency and safety in many other ways. The new flat-panel electronic display media, for example, are matrix-addressed solid-state devices that have the potential to replace bulky vacuum tube devices (cathode ray tubes). The potential here is for much higher reliability, graceful degradation (as opposed to catastrophic failure), and reduced workstation volume, weight, and power consumption. Advancing computer graphics technology can provide a means of driving the new electronic display media in two-dimensional, pseudo three-dimensional, and in stereo three-dimensional modes that may greatly enhance the effectiveness of monitoring and control modes for a variety of functions such as construction, rendezvous, docking, and proximity operations. The flat-panel displays may be applied in conjunction with emerging microprocessor technology to provide the multifunction controls which may greatly consolidate the man/machine interface and also contribute to greatly reduced weight, volume, and power consumption.

The principles of fault-tolerant hardware and software design (to be discussed in sections below) can also be applied to the man/machine interface as a means of highly automating the interface. Using these principles in conjunction with an appropriate architecture of control, display, display generator, and workstation computer components and associated software, the potential exists for man/machine interfaces that have the same level of fault-tolerance and redundancy as the onboard computer systems which will provide automation functions.

Voice Recognition and Natural Language Understanding

AI research in natural language and speech is aimed at reducing the natural language (or speech) input to a representation in the computer that captures the intended meaning. In "understanding" speech, the input is a digitized acoustic signal, while in "understanding" a natural language, the input is text, usually entered from a keyboard.

While many problems remain to be solved, limited but useful natural language systems are already commercially available. The problem of understanding speech is much more difficult because of signal interpretation difficulties. However, usable technology for speech input has become increasingly available. Subsystems are now available that can "recognize" words, or even sentences spoken by different persons, subject to limitations in vocabulary and sentence construction. Experience with commercial natural-language interfaces to data bases has proved the usefulness of natural-language technology.

Speech coding. *"Speech coding is a set of techniques that transform an analog speech wave to some digital representation, allowing improved use of transmission and storage media. Analog solutions notwithstanding, money can be saved if two or more voice* *channels can be multiplexed on the same pair of wires now used for one channel. New services can be more readily and inexpensively provided if those two wires can handle both voice and data indiscriminately. Systems that incorporate digital speech storage can save both memory and bandwidth by using speech coding techniques that operate at lower bit rates. Will optical fiber obviate the need to compress speech for transmission? Possibly, but embedded plant and other band-limited environments will continue to exist, so speech coding will remain desirable"* (Andrews, 1984).

Pulse-code modulation (PCM) is the standard for digital voice transmission in the telephone network. Other techniques of speech coding include adaptive differential pulse-code modulation (ADPCM), subband coding, linear predictive coding (LPC), and multiple linear predictive coding.

"Probably the most important advancement in speech coding products is VLSI. Three years ago it would have been difficult to find linear predictive coders/decoders priced for less than $12,000. Today, we can anticipate coders of greater complexity for far less and can predict rapid and dramatic cost/performance improvements over the next few years.

"Until the early 1980's implementations of LPC voice coders required very smart circuit design using discrete TTL with microprocessors onboard for data management and some high-level decision making. The situation has changed with the development of digital signal processing (DSP) chips. New DSP entries offer higher level language programming and improved development systems, which make them increasingly easier to program. Inexpensive coders/decoders are being offered, and applications are becoming increasingly evident" (Andrews, 1984).

Automatic speech recognition. Automatic speech recognition, ASR, may have reached something of a plateau. Although research in this area accelerated in the late 1960's and continued throughout the 1970's, the goal - the ability to recognize unrestricted vocabularies of continuous speech from any speaker - remains distant and certainly will not be realized until artificial intelligence progresses far beyond its current state.

"Isolated word recognition, as the name implies, requires that a short interval of silence be inserted between utterances. Connected word recognition requires the user only to enunciate each word very accurately. Continuous-speech recognition would allow speakers to use a conversational mode, in which utterances typically run together and the context alters the pronunciation of a word. It is in fact these co-articulatory effects and their variations among speakers that make continuous recognition so formidable" (Andrews, 1984).

Three major issues concern speech recognition researchers: speaker independence, vocabulary size, and isolated versus connected speech processing. Speaker independence is the degree to which the system can recognize speech spoken by arbitrary speakers. While the goal is clearly to achieve complete independence, this has not been achieved. Currently, speaker independent systems support only a very limited vocabulary.

Vocabulary size affects both storage requirements and processing time. The larger the vocabulary the more (fast) storage is required. Moreover, to increase recognition accuracy, more storage is needed for each item in the vocabulary. The recognition process itself amounts to searching the vocabulary and comparing it against the input. The larger the vocabulary, the longer the processing time, thereby limiting its usefulness in an interactive environment.

Isolated word recognition systems have been far more successful than continuous speech recognition. In isolated word recognition systems, each word must be clearly delimited (e.g., by a pause); each word is then treated as an independent entity and is processed separately. Continuous speech requires, in addition, that word boundaries be identified - a complex task that has eluded solution.

Currently, systems are available that operate in real time, recognizing a vocabulary of about 1,000 words of isolated speech. These systems are speaker dependent, and the amount of training required varies among the systems. Similar systems for recognizing 5,000 words are within the state of the art but not yet available. One of the major problems in such large systems is the long and tedious training sessions. Also, beyond feasibility proof, it is not clear whether applications exist in which such large vocabulary is needed for (the unnatural) isolated word recognition.

Speaker-independent systems exist, but their vocabulary is limited to a few tens of words. It is worthwhile to notice that constructing a speaker-independent system to recognize the (sound of) the alphabet has thus far not achieved sufficient reliability. Thus, spelling out words not in the vocabulary is not a viable option (doing so in a speaker-dependent system with proper isolation is feasible).

A very common application is one that requires recognition of spoken digits. Due to the limited vocabulary (about 150 templates are required) continuous speech digit recognition systems are available (e.g., one by Verbex, Inc.). These systems are useful for inventory control, service and repair, etc.

Interestingly enough, most existing systems are quite insensitive to surrounding noise as long as a single dominant speaker can be identified. This means that speech recognition can be done in the presence of mechanical noise such as in a machine room or inside a vehicle.

The advent of processing technology has prompted DARPA to initiate a new program in speech recognition. The program goals are to achieve accurate, continuous speech recognition for large vocabularies (about 10,000 words). Significant progress may occur in the next decade.

Speech synthesis. In speech synthesis, a computer generates audible words for output instead of printing or displaying the words. Advantages of speech synthesis over printed output are naturalness of communication and the ability to communicate by listening, allowing the person involved to use vision for other tasks.

Two fundamentally different types of speech synthesis systems may be identified - limited vocabulary and unlimited vocabulary. Limited vocabulary systems use prerecorded, typically digitally encoded, speech, often organized as individual words. A computer system determines the order of the words, and a general output capability is achieved, limited only by the size of the stored vocabulary.

Unlimited vocabulary systems take arbitrary text as input, synthesize an acoustic waveform via appropriate algorithms, and output the waveform as audible voice. The algorithms analyze the input text and transform it into one or more intermediate representations, such as a phonetic representation, based on a set of rules. The actual acoustic waveform is derived from an intermediate representation. The major limitation of such a system is that any set of rules will cause mispronunciation when dealing with a large, inconsistent, natural language such as English. To circumvent this problem, most of these systems use an exception dictionary to hold information on the pronunciation of words that are exceptions to the internal rules.

Limited vocabulary systems have been attractive in the past for applications in which relatively small vocabulary size is not a drawback and high speech quality is required. However, unlimited vocabulary systems have recently begun to approach human speech in terms of comprehension if not overall quality. Because of the high level of quality currently achieved by current unlimited vocabulary systems, only small increments of progress may be expected in the next decade in terms of speech quality. However, even current technology is likely to be useful in the Space Station.

Speaker verification. *"Speaker verification is the process of automatically identifying an individual based on voice characteristics. Speaker verification has achieved the same degree of maturity as the other voice technologies we have discussed and could be* *an essential ingredient in many applications. By properly engineering an application using a good speaker-verification technique, product developers can achieve satisfactory performance.*

"Verification involves a comparison between a specific utterance of the speaker and a stored reference template of that speaker's utterance. The term verification is used because the speaker would have claimed an identity prior to being verified. Some key-in procedure would be used, and a voice comparison would lead to an accept or reject decision" (Andrews, 1984).

Natural language understanding. Several natural language understanding systems exist today on the market, and all work reasonably within a limited task domain and a well defined context. Thus, query to a data base can be made with a natural language interface where the interface translates natural language sentences into the formal query language and displays the answer. Currently, most natural language understanding systems interface with a single data base. Attempts have been made to construct a single interface to several data bases and have the interface itself deduce which data base to interrogate. Better interfaces of that kind are likely to be available soon.

Performance of natural language understanding systems will increase substantially when new hardware architectures are introduced. At the execution level, natural language understanding requires massive searches and comparisons which can to a large extent be parallelized so that execution time is reduced. The new generation of computers, those consisting of a large number of cooperating processes, is particularly well suited for natural language understanding purposes. It is not inconceivable that specially designed multiprocessors dedicated to natural language understanding will be part of every computing system.

Computer Vision

The most important noncontact sensing mode used in robotics today is vision. The last 25 years has seen much progress in many applications of computer vision, including document processing (character recognition), microscopy, radiology, industrial automation (for example, inspection and robot vision), remote sensing, navigation, and reconnaissance, to name only the major ones.

"The general goal of computer vision is to analyze images of a given scene and recognize the content of the scene. Many types of scenes are essentially two-dimensional. We extract features, such as edges, from the image, or we segment the image into regions, thus obtaining a map-like representation consisting of image features labeled with their property values. Grouping processes can then be used to obtain improved maps from the initial one. The maps can, in turn, be represented by abstract relational structures in which, for example, nodes represent regions among regions. Finally, these structures are matched against stored models, which are generalized relational structures representing classes of maps that correspond to general types of images. Successful matches identify image parts, and give us a structural description of the image in terms of known entities.

"The most commonly used method of 2-D segmentation is based on pixel clustering and classification. In this approach, the scene is composed of flat, uniformly illuminated surfaces of approximately constant reflectivity, giving rise in the image to regions of approximately constant gray level. The regions' gray-level ranges can be determined by examining the images's histogram (a bar graph showing how often each gray level occurs in the image); regions of constant gray level give rise to peaks on the histogram. The image can thus be segmented into regions by finding gray-level ranges, each of which contains just one peak; the sets of pixels lying in each range thus define a segmentation of the image.

"In other situations, notably in robot vision applications, the scenes to be described are fundamentally three dimensional, involving substantial surface relief and object occlusion. Successfully analyzing images of such scenes requires a more elaborate

approach in which the three-dimensional nature of the scenes is taken into account. Here, the key is to infer the surface orientation at each image point. Clues to surface orientation are derived directly from shading, or gray-level variation, in the image. Alternatively, two-dimensional segmentation feature extraction techniques are first applied to the image to extract such features as surface contours and texture primitives, and surface orientation clues are then derived from contour shapes or from variations in texture. Using the surface orientation map, we once again apply feature extraction and segmentation techniques to yield a segmentation into visible parts of bodies or objects. These in turn are represented by a relational structure. Finally, the structure is matched against models to yield an interpretation of the scene in terms of known objects. The matching process is more difficult in the three-dimensional case than in the two-dimensional case because the image shows only one side of each object, and objects may partially occlude one another. We are not simply "matching" a model with the observed structure, but rather are verifying that the model could give rise to that structure under appropriate viewing conditions. Given images taken from different viewpoints, a three-dimensional model of the scene can be constructed directly, using stereomapping techniques.

"An important method of 3-D shape recovery is based on analysis of the gray level variations (shading) in the image. A uniformly illuminated curved surface of constant reflectivity in the scene will give rise to a region of varying gray level in the image, since the brightness of the surface at a point depends on its orientation relative to light source and viewing directions. The 3-D shape of the surface is not uniquely determined by the shading, but shading strongly constrains it, and under some circumstances, we can infer a plausible shape solely from shading information.

"Information about the 3-D shapes of the surfaces that appear in an image can be used to segment the image into regions that correspond to surface sections, rather than into regions of uniform brightness.

"Matching with a 2-D model involves measuring properties of and relations among the regions or features in the image, representing this information in the form of a relational structure, and matching this structure to stored models, which are generalized descriptions defining object classes. Even in two dimensions, such models are often very difficult to formulate, since the constraints on the allowable property values and relations are hard to define.

"In three dimensions, the problem is rendered even more difficult because only one side of an object is visible in an image; the image description is 2-D, while the stored object models are presumably 3-D, object-centered representations. Matching with a 3-D model involves using the structure derived from the image to define constraints on the objects that could have given rise to the image and finding object models that satisfy those constraints" (Fu et al., 1984).

Suppliers of vision systems include Machine Intelligence Corporation, Automatix, General Electric, and Bausch and Lomb. These systems can identify and locate objects in a controlled environment with the following restrictions:

- The number of possible objects that can be identified is limited.
- The number of objects in the scene is limited.
- The objects do not overlap.
- The object is always viewed vertically.
- The image features of an object are extracted from its binary image (silhouette).
- The objects are illuminated so as to obtain high dark-to-light contrast.

Typically, a system is trained to distinguish among objects by showing it sample objects. It will find outlines of each object and, using various techniques, develop a classification so it can distinguish the different types. In general, research in this area will lead to more flexibility in the images that can be processed, including the following capabilities:

- Identifying objects that overlap
- Accommodating for a change in perspective
- Fewer requirements on lighting conditions

"Most successful applications of computer vision have involved relatively simple domains and have been primarily two-dimensional. For example, in robots vision, systems that recognize parts on a belt (well-illuminated, nonoverlapping, in specific 3-D orientations) are not hard to build, but systems that recognize parts in a bin (shadowed, overlapping, arbitrarily oriented) are still in the research stage. Existing techniques will in principle handle such complex situations, but they need to be refined and tested extensively before they can be used in practice" (Fu et al., 1984).

For robotic applications, solid-state cameras are preferred over those with vacuum-tube imagers such as vidicons because of their ruggedness, low image distortion, low power requirements, and small size. Today's solid-state television cameras can operate on either visible or infrared light. The highest image resolution available (800 by 800 pixels) is now about twice that of broadcast television, and the fastest cameras can take 2,000 pictures per second (as compared to 30 for broadcasting). Nondestructive-readout cameras can store an image for hours, and the image can also be modified by a computer while it is stored. Within about 10 years, 2,000- by 2,000-pixel resolutions should be available. But, to reduce the amount of image data to be processed, some cameras may have only a small high-resolution region near the center of their field of view ("foveal cameras").

An interesting class of vision sensors is the "eye-in-finger" approach. A linear array of light transmitters and receivers indicates when the light beam is broken by an object that is between the fingers. A two-dimensional binary image is obtained by moving the effector. Three linear arrays are used, one on each side and one on the bottom. This type of sensor could be useful in directing mechanical fingers in grasping an object.

Relational Data Bases

There exist three major types of data base management systems: the hierarchical or tree model, the network or link model, and the relational model. The latter is the newest approach and a dearth of commercially available systems may be partially explained by the necessarily large amounts of computing power and storage required, which, in the past, have been generally unavailable and/or expensive. However, in the case of the hierarchical or network models, for a large and complicated data base the schema and the manner in which users may access it may become very complex. The relational approach strives to avoid many of these drawbacks. It views the logical data base as a simple collection of two dimensional tables called relations. The columns of the table correspond to the data items and the rows to the logical records. The tables are easily understood and handled by users with little or no training in programming, and involve no consideration of positional, pointer, or access path aspects.

These tables are formally a mathematical set and can be manipulated by relational algebra procedures, such as JOIN and PROJECT. JOIN links two tables based upon a specified data item from each. The result is a third table containing those rows where a Boolean condition (e.g., equal) between the specified data items is satisfied. PROJECT extracts columns from one or more tables and creates a new table containing a subset of the original(s) based upon a Boolean condition. Using these and other set operations, it is possible to manipulate or extract any information in the data base.

Besides being easy to understand, another major advantage is the ease with which the data base can be changed. This holds true not only for adding and deleting records but also for creating new tables, adding columns, etc. It is also easy to ask a relational data base new and unusual questions, because anything can be related to anything else and all the data are accessible from any point.

In order to support automation, as much data as possible describing the design of the Space Station must be captured in a machine-readable format in a permanent Space Station design Data Base. These data include motivation for elements of the design, indication as to how parts are assembled and disassembled, cautions concerning the handling of objects, etc. Although it will not be immediately useful, the availability of these data will be absolutely crucial in the future when artificial intelligence technology evolves sufficiently to allow a computer to understand it. It will then be useful in a wide variety of automation on the Space Station, including automatic guidance of robots, equipment monitoring, malfunction detection, diagnosis, and the planning and execution of repair procedures.

The information must be captured as it is developed. This will be relatively easy to achieve in the case of computer-aided design data. However, it will also be necessary to get the designers to supply written descriptions of the reasons for their design choices and, where relevant, how the equipment in the designs is supposed to operate. Most difficult of all will be to capture information from engineering drawings that are not produced with a CAD system. Either the drawings must be scanned and the compressed facsimile data stored, or the original paper records must be safely archived and indexed for later scanning.

Distributed Processing

There are two distinct types of distributed processing required for the Space Station which are characterized by different requirements and implementation hardware. Onboard systems are characterized by heterogeneity, specialized computing requirements, and the need for flight-qualified hardware. Ground systems are expected to use high-performance commercial machines in a much different computing environment involving large distributed data bases and shared computing resources.

Onboard distributed processing. The onboard system will have a hierarchy of computing tasks from overall system control and autonomous maintenance functions to dedicated computers embedded within spacecraft subsystems and high-performance general- and special-purpose processors for processing data from various experimental payloads. It is likely that different processor configurations will be needed at different places in the system and the embedded nature of many processors will necessitate specialized interconnections and dedication of functions to specific processing sites.

For onboard distributed systems, as with any new technology, a learning curve is involved in their development. The Johnson Space Center has instituted an architecture study, conducted by the C.S. Draper Laboratory, for the development of a fault-tolerant distributed processing system for the Space Station. The Galileo project at the Jet Propulsion Laboratory will employ distributed processors on a spacecraft. This system can autonomously generate commands onboard for spacecraft control and handling of unexpected faults. Also the Air Force has developed distributed onboard processing systems. Through these and other projects, a limited knowledge base of project management, system architecture, integration, testing, and of parts procurement and development has been developed within NASA. However, the Space Station will be much more complex than any onboard distributed system of the past and a number of important research and development issues must be addressed long before systems of this complexity are constructed.

Ground-based distributed processing. It is expected that ground-based processing will make use of local area networks that are commercially available and that maintain the integrity of large data bases. Technology of this type is being developed, a good example being the LOCUS system developed for DARPA at UCLA. Systems of this type have the following characteristics:

(1) For high availability, a consistent name space is used for files or objects throughout the distributed system, and

the system is made to appear homogeneous. Objects can be reached from more than one computer in the system so that if one machine fails it is possible to switch to another computer and continue the computations. All objects paged to disk are transparently stored at two different sites so that if any storage site fails (i.e., its host computer or peripherals) the information remains available.

(2) Data Integrity depends upon detecting faults before fault-damaged data is written to the disks. In current systems this depends upon the fault-detection capabilities of commercial processors which are reasonably good but by no means comprehensive. A number of transient faults may occur and go undetected. Techniques should be developed to improve fault diagnosis in the ground processors if an occasional corruption of data bases cannot be tolerated.

Fault-Tolerant Processing

Fault-tolerant computing implies the development of computing systems which can continue correct computations in the presence of faults. As systems become more complex the probability of failures increases. Current space programs have been especially concerned with "single event" upsets which are transient disturbances which can create errors in memory and prevent and/or invalidate subsequent computations unless prompt recovery intervention takes place. Less frequently, components will fail, requiring redundant hardware to restore proper operation. Spare components are included in the design along with automated fault diagnosis and recovery mechanisms.

A number of fault-tolerant machines have been implemented and this can be viewed as a relatively mature technology. NASA has been the leader among government agencies in the development of fault-tolerant computing. Three basic approaches have been employed in both the NASA and other fault-tolerant computer designs. The first (triplication with voting) uses groups of three computers which simultaneously perform identical computations. Their outputs are voted to mask the effects of a fault in any single machine. These massively redundant and relatively expensive approaches have been employed for critical applications such as aircraft control. A second approach is to operate computers in pairs and compare their outputs to detect disagreements. If a disagreement is detected, a diagnostic program is run to find the faulty machine. This approach often fails for transient faults because both machines will pass a diagnostic, but the machine which had the transient fault may have undetectably damaged information in memory (so the two machines will continue to disagree when restarted). The third approach uses self-checking computers, i.e., computers which are designed with internal checking logic and which can detect their own errors during normal operation. It has been shown that a computer can be made to be self-checking with an additional complexity of about 10 percent. For noncritical applications, a single self-checking computer is powered with one or more unpowered backup spares. If the active machine fails, the spare is powered and the computation is restarted. For critical computations, two self-checking machines perform the same computations. If one fails, a spare is substituted for the faulty machine. The other machine initializes the newly activated spare machine and a configuration of two machines is reestablished. Self-checking computers were developed for long-life deep space missions. They require less power and provide longer life for a given amount of redundancy than does the triplicated approach.

Computer Technology

By the time the Space Station becomes operational, VLSI circuits of capabilities similar to VHSIC phase 1 devices should be available for use. Single chip processors are expected which will be capable of executing up to several million instructions per second, and it will be possible to fly much larger memories than is currently possible. It should also be possible to develop custom chips with complexity equivalent to 40,000 gates and clock speeds of from 20 to 40 mHz. It is expected that these custom chips will be used for circuits of two basic types. Building block chips will provide standard communications interfaces, fault-tolerance support, and other functions used repeatedly in connecting the various processors into the Station's distributed computing system. Custom chips will also be needed for preprocessing very high rate payload data.

Software

Software includes programming languages, operating systems, and software engineering methods and tools (Reference NASA TM 85631, NASA Computer Science Research Program Plan, March 1983).

In scientific and engineering fields, FORTRAN is, and will continue to be, a primary programming language. More and more "Fourth Generation" languages are appearing which provide easier user interface to data bases, spread sheets, and other business applications. For embedded systems, which will exist on the Space Station, the DOD Ada language is becoming a standard. Much effort is currently being expended in developing Ada compilers, run-time systems, and support environments. Special-purpose languages for list processing and artificial intelligence applications include LISP and PROLOG. These languages are also being refined and standardized.

Primary drivers in the development of modern programming languages and applications generators are cost-effective development, maintenance, and reliability. If computer programs can be written more automatically, then there is less chance of human error, meaning more efficient code development (cost effective) and fewer mistakes (reliability). Also, if programming languages are standardized, then programs (such as subroutines, modules, and packages) can be exchanged and reused on different computers for different applications. Again, this increases the reliability by employing well-used software components and reduces the cost of developing code.

Software reliability techniques have been suggested, including N-version programming and recovery blocks. Such techniques are used in cases of critical software where high reliability is required. However, the effectiveness of these techniques is not yet proven, and additional research is needed.

High-level programming languages, debugging tools, and operating system utilities have improved both the productivity and reliability of software development. However, the process of describing software requirements and converting these into object code still involves many manual steps, prone to human error.

Information Networks

Information networks will provide for the distribution and communication of information and data throughout the Space Station in support of the distributed subsystem functions and processing. With the emphasis on inclusion of high degrees of automation and robotics in the Space Station, the anticipated data networking poses complex technological requirements. Preliminary investigations have established three primary requirements for a space station information system.

- High performance: Real-time video, image processing, station maintenance, spacecraft rendezvous, and proximity operations will require data distribution at rates exceeding 108 bits per second.

- Reliability/fault tolerance: The integrity of the Space Station and the lives of its personnel will depend on continuous and reliable distribution of data for monitoring and control of the Station.

- Extensibility/modularity: As the Space Station expands and its emphases change, the information system must evolve gracefully.

It is believed that one or more networks will be capable of simultaneously providing the necessary data communications and computation capacity, fault tolerance, and modularity. Many network types are being developed for commercial and industrial use, and much research is being conducted in university and industrial laboratories. Ethernet, which is a linear bus-type network, is the most mature commercial/industrial Local Area Network and possesses the extensibility/modularity requirement, but does not possess the high-performance and fault-tolerant requirements. Hyperchannel is an example of a high-performance network with extensibility but does not have any fault-tolerant attributes. These are research efforts on fault-tolerant networks being conducted (Ohio State, C.S. Draper Labs), and these networks have the extensibility requirement but lack high performance. The concept of an integrated network approach where video, voice, and data are simultaneously served is being researched by Bell, but at this time is still relatively low performance. The high-performance requirement will best be served by the use of fiber optic and integrated optic components and devices (i.e., optic node), and the fault-tolerant requirement will best be met by the selection of a mesh architecture or topology that would provide simultaneous or alternate data communication paths. Currently, there does not exist a commercial, industrial, or research network that simultaneously possesses the high performance, fault tolerance, and extensibility requirements. NASA has undertaken technology to develop information networking that simultaneously meets these requirements.

RESEARCH RECOMMENDATIONS

To ensure the evolution of an automated Space Station, research must be focused on those automation technologies which directly fulfill the needs of the Space Station. The following recommendations for research efforts emphasize these needs. They are also broken down into the same twelve categories used in the previous section.

Teleoperation and Robotics

NASA research in teleoperation being supported at OAST must be expanded in order to have an impact on the Space Station. In particular, work is needed in effectors, sensors, control systems, teleoperation procedures, teleoperation workstations, and sensory feedback techniques. Current earth-bound robots are not equipped to deal with the new and hostile environment encountered in space. Zero gravity will introduce complex kinematics/ dynamics problems, and allow the robot to exploit novel forms of locomotion not feasible on Earth. Problems involving thermal gradients and radiation must also be researched to ensure that a robot will be robust in the space environment. The adequacy of these research results can be partially tested in neutral buoyancy tanks, but true adequacy can be determined only by experiments in space.

Some important research topics for manipulators are as follows:

- Design of manipulators: Zero gravity will allow manipulators to be longer and thinner than conventional industrial models, some of which are so bulky as to resemble machine tools. However, there is currently no adequate theory for controlling a manipulator which has flexible, limber links between its joints. This will limit the slenderness that can be achieved with available materials. Light, stiff materials such as carbon fiber composites, or even titanium, may be cost-effective in a space manipulator. Research in actuators should concentrate on improving power-to-weight ratios and energy efficiency. A possible starting point is the remotely operated vehicles (ROV's) now being developed for undersea work platforms. Many of the repair and inspection tasks for offshore oil platforms and undersea pipes are similar to those in space. Another similarity is the use of lightweight arms (because of the buoyancy of the water).

- An adaptive robot arm: Other things being equal, it will probably be advisable to trade off accuracy and repeatability to obtain finer resolution in designing an adaptive robot arm. The external sensors allow closed-loop control that compensates for the lack of those characteristics. This approach also compensates automatically for wear, minor structural deformation, and other kinds of performance degradation that may result from extended operation.

- A general-purpose hand: Much research is needed in understanding the control techniques of a multiple-fingered hand using nine or more degrees of freedom.

- Robot repair of robots: The AEC at Oak Ridge has developed robotic arms that are modular, so that one arm can replace the portion of a failed arm of another. This type of arm design would be important for space teleoperation.
- Wrist socket interface: A standard design for a wrist socket interface would be extremely useful. It should perform the following functions:
  - Provide strong mechanical support for the end effector (hand, tool, sensor, etc.)
  - Protect the end effector against excessive force and/or torque in any direction. For example, it might allow the end effector to break away from the wrist, triggering shutdown of the arm. The end effector should still be retained, for example, by a tether.
  - Protect the arm - e.g., by allowing the tether to separate under excessive tension
  - Automatically return the end effector to its normal position after breakaway when the excessive load is removed
  - Allow quick connection and disconnection
  - Interchangeability of special tools
  - Transfer power to the end effector
  - Transfer information to and from the end effector
  - Transfer fluid (air, hydraulic fluid, propellant, etc.) to and/or from the end effector
- Task mechanics: The least developed, and perhaps most important, component of dexterity is knowledge on the part of the manipulation system of what will work. Very little is known about how parts interact and how a hand can interact with a part. Strategies and tactics for manipulation are needed that will reduce the number of conceptual degrees of freedom in an assembly problem so that it can be solved. Primitive manipulation operations must be developed that will permit sophisticated actions with reasonably straightforward generation schemes. Preliminary progress in this area points the way to controlling uncertainty without resorting to sensing. Recent work has begun to address the fundamentals of task mechanics, and industrial practitioners have amassed substantial experience, though most of it has not been codified. Research in this area, if adequately emphasized and supported, will have the most important impact on improving robot dexterity.

There has been little research in the analysis of touch sensor pressure patterns. Of great importance is the time sequence of these patterns and their analysis. Other research topics include development of space-rated touch sensor integration. Also important is the incorporation of sensor information into automatically produced plans. Other noncontact sensing applications to be looked at include acoustic, chemical, and temperature sensing.

Sensor-based control is a particularly important area. In terms of manipulation, the ability to use data from sensors that move with the hand is both crucially important and very difficult. Except for force-sensing wrists, little has been done in this area. Fundamental and development work are both required.

Mobile robots will be essential on the Space Station. Robot mobility can be improved in three respects - sensing, control, and design.

- Sensing: The problem of providing a mobile system with information about where it is, the direction of its motion, and the speed of its motion are very important. While this problem is common to a variety of mobile technologies, the bandwidths, needed for legged systems as we currently envision them, are particularly severe.

Satellite-based systems will probably not provide the kind of fine-grain information needed. Specialized techniques may prove acceptable in specialized environments. The single most important barrier to achieving useful mobile systems that do not have direct human control will be the task of determining the detailed shape of the terrain along the paths of interest. This problem involves sensing, perception, and spatial representation. The difficulty of this problem is related to the generality of the situations in which the system will be expected to work. The speed of locomotion may also be a factor.

- Control: Most current autonomous vehicle research deals only with flat floors. Solutions to most problems on flat floors are within sight. Research is needed to find techniques that will provide mobility where the terrain is not flat. Even with complete knowledge of the terrain, there are substantial control and planning problems that must be solved before mobile systems will negotiate difficult terrain. Solutions to this sort of terrain problem will involve the mechanics of locomotion, control, planning, and heavy doses of geometric representation and reasoning. While medium-grain knowledge of the terrain will be important, so will techniques that make a system inherently insensitive to minor variations. Substantial mechanical design of new mechanisms will be involved in building systems that can negotiate rough terrain.

- Design:

  - Self-contained power: Mobile systems will need to provide their own power. While it does not appear to be too hard to carry a power supply at large scale, say gross vehicle weights in excess of a ton, this is a very hard engineering problem at smaller scale, say human size.

  - Optimize payload, range, and speed: If a locomotion system is to be a transportation system, it must carry a payload, and the distance that it must carry the payload without intervention is of considerable importance. The speed of transport is also important. Part of the payload, like computing equipment, communication equipment, fuel, etc., may be needed for locomotion. It will usually be desirable to transport something that is not a part of the locomotion system itself, like a pair of manipulators or a sensory system. Consideration of these factors is an optimization problem for the system architect and the mechanical designer. Special control strategies may also be important.

"*Robot programming languages are also in need of concentrated research. Needs include task-level programming to incorporate planning, the automatic decomposition of tasks into subtasks, and the accommodation of other features often found in AI-related projects. Also, robots need procedures for automatic and general-purpose error recovery. In spite of the need for advanced features like task-level programming, programming language for robot motion that is both conventional and standard would greatly stimulate progress in these areas*" (Jarvis, 1984).

Expert Systems

Research in expert systems should be focused on the special needs of the Space Station in maintenance and control of Space Station subsystems and manufacturing processes.

The representation of knowledge is a key issue in expert systems, since the representation forms the basis for reasoning and explanation. The representation chosen depends on the nature of the application.

Important questions to be studied include

- How are elements of one body of knowledge related to one another?

- How can reasoning about space and time be carried out?

- How can one represent knowledge for use in determining the causes of events; i.e., how can one represent causal models?

- How can one represent "knowing by doing" procedural-type of knowledge, i.e., heuristic information about what to do and how best to do it?

The end product would be both general-purpose and application-oriented knowledge representations suitable for various Space Station applications.

Research in knowledge representation should be carried out in the context of both specific Space Station applications and general representation issues. Thus, knowledge representation would be developed for each class of expert system applications, such as maintenance, repair, control of subsystems, and man/machine interaction. It is expected that maintenance and repair will require representations that are strong in causal explanation, that control subsystems will require representations that have a fast response, and that man-machine interaction will utilize representations capable of providing various levels of explanation. Much research needs to be done in real-time expert systems.

The ultimate goal is to allow an expert to encode his own knowledge directly without the need for a knowledge engineer, to refine that knowledge, and to verify the correctness of the knowledge base. The expert system would suggest possible modifications and handle "bookkeeping" functions.

The following research tasks would be appropriate:

- Initial knowledge acquisition: Since much of the role of the knowledge engineer is to aid in the structuring and formalization of the problem domain, it is not clear that this can be done automatically. An appropriate research task would be to develop a menu of models that would be useful for a particular class of applications. The expert, in a dialogue with the system, would select the most appropriate data structures. It is expected that natural language interaction might be important here.

- Knowledge verification: The builders of a knowledge-based expert system must ensure that the system will give its users accurate advice or correct solutions to their problems. The process of verifying that a system is accurate and reliable involves testing and refining the system's knowledge in order to discover and correct a variety of errors that can arise during the process of transferring expertise from a human expert to a computer system. An automated assistant for knowledge-base debugging has been used in the ONCOCIN system. The automated assistant checks for inconsistencies and gaps in the knowledge base, helps the experts and knowledge engineers to communicate with each other, and provides a clear and understandable display of the knowledge as the system will use it. This research task would develop a similar assistant for knowledge-base debugging.

- Knowledge refinement: An important tool for refining a knowledge base is a facility for displaying the existing base in some graphical or structured manner. This task would develop tools for interacting with an expert to indicate gaps in the data base for which knowledge or procedures should be supplied.

It is important to be able to reason based on incomplete or uncertain evidence. Research in this area would provide techniques suitable for such reasoning focused on specific applications. This research would investigate techniques in Bayesian reasoning, evidential reasoning, fuzzy reasoning, and nonprobabilistic approaches (e.g., truth maintenance) to find those that are appropriate for the Space Station applications.

There are various kinds of explanation that might be provided in an expert system:

- What is the immediate goal?

- What is the justification for an action?

- How will a particular action contribute to the goal?

- Why is that a good choice of methods to accomplish the goal?

The end product of this research would be techniques for supporting various types of explanation. This research task would examine existing explanation systems, choose those that are appropriate for the various applications, and develop new explanation systems. It may be necessary to develop special representations for domain-specific applications.

Most expert systems are not well suited to problem domains where much of the expert knowledge is procedural and where tests and actions need to be carried out in a particular time order. Yet, this is exactly the type of knowledge that is common to the problem of fault diagnosis in complex spacecraft systems. This research task would develop procedural expert systems that explicitly represent procedural knowledge while still retaining the benefits of traditional expert systems. The basis of the scheme is to use a representation that is sufficiently rich to describe arbitrary sequences of actions in a simple and natural way, while at the same time to avoid explicit procedure "calling." Schemes for explicitly representing and using expert knowledge of a procedural kind must be developed to bridge the gap between the procedural and declarative languages. In addition, the representation of temporal domains needs to be properly formalized, and suitable techniques for truth maintenance developed.

Research needs to continue on symbolic processors that are capable of dealing with the types of symbolic manipulation often found in AI applications. There is no reason to expect that the addition of incremental amounts of knowledge will lead to global understanding. To be able to understand, the system must be able to generate higher level concepts by comparing and generalizing problem situations or groups of knowledge elements. No such ability has been provided in existing systems. This ability to make comparisons and to determine similarity is a crucial part of generalization and learning. A learning expert system would be one that learns from experience, similar to the way a human expert broadens his knowledge with experience. This is a very difficult research area. An initial project might be an interactive scheduler that learns as it is guided.

Planning Systems

Planning systems have additional research needs. There are difficult problems in representing time and space for automatic planning. While people have little trouble in dealing with time and space parameters, it is difficult to formally represent the implicit time and space relationships that exist in a situation in a computationally effective form. This research is needed for automatic planning in general.

Space Station representation research should be focused on representing the objects and their relationships as well as how the world of the Space Station is affected by actions. One must somehow indicate the properties of objects in this world that are important to actions, such as movability, danger, hardness, etc.

Interactive planning research should focus on the development of a Planning Assistant for use by the astronauts. A major focus is on suitable man/machine interfaces such as high-resolution graphics displays.

An important part of the planning process is using portions of the previous plans to solve a current problem.

Planning under uncertainty is one of the most difficult of the research areas, but is most crucial for autonomous operation of robots and vehicles. Some of the current DARPA research concerning planning for an autonomous land vehicle, and work in autonomous robots at Carnegie-Mellon University, Stanford University, and SRI International will be pertinent here.

Realization of the full benefits of multiagent systems will require research advances in the reasoning abilities of the individual agents and in interagent coordination and communication strategies. For multiagent planning, it is necessary to carry out research in models of actions, belief of agents, and communication among agents.

Man/Machine Interface

Although much technology is becoming available in the area of man/machine interface, there are many remaining research problems. In the fields of electronic display media, computer graphics, and workstation design, the thrust of most R&D efforts is aimed at industrial and commercial applications. These applications, in most instances, do not have the stringent visual performance requirements and certainly do not have the physical constraints (weight, power, and volume) that the Space Station application will entail.

Research is needed to develop appropriate display media, computer graphics, consolidated controls, and workstation design technology. In the field of display media, flat-panel display technologies require development to overcome present limitations on screen size, uniformity, resolution, luminance efficiency, and color capability. In the field of computer graphics, research is required to refine and microminaturize graphics engine technology and to develop appropriate two-dimensional, pseudo three-dimensional, and stereo three-dimensional display formats for Space Station functions such as systems monitoring, construction, rendezvous, docking, and proximity operations. In the field of controls consolidation, research is needed to develop appropriate multifunction interfaces using flat-panel, tactile, touch, and voice I/O technologies. In the field of workstation design, research is needed to expand the design methods and concepts and to provide human factors guidelines for optimum human interface for the monitoring and control of automated and knowledge-based systems.

Voice Recognition and Natural Language Understanding

In addition to extending capabilities of natural language access to data bases, much of the current research in natural language is directed towards determining the ways in which the context of an utterance contributes to its meaning and developing methods for using contextual information when interpreting utterances. For example, consider the following pairs of utterances:

(1) SAM: The locknut should be tight.
JOE: I've done it.

(2) SAM: Has the air filter been removed?
JOE: I've done it.

Although Joe's words are the same in both cases, and both state that some action has been completed, they each refer to different actions - in one case, tightening the locknut; in the other, removing the air filter. The meanings can be determined only by knowing what has been said and what is happening.

Some of the basic research issues being addressed are

- Interpreting extended dialogues and texts (e.g., narratives, written reports) where the meaning depends on the context
- Interpreting indirect or subtle utterances, such as recognizing that "Can you reach the salt?" is a request for the salt
- Developing ways of expressing the more subtle meanings of sentences and texts
- Interpreting language that is "ungrammatical," e.g., slang or dialects (This is particularly of interest for spoken language.)

Many of the research issues of speech and natural language understanding will benefit from DARPA research in these topics. The effort here should consist of adapting research and devices to the space environment.

Computer Vision

Although vision systems are becoming available, there are many remaining research problems. Basic research in computational vision is devoted to understanding how further knowledge and reasoning can be used to interpret images, particularly so-called natural scenes, such as those found outdoors, where there are no restrictions on the environment, the objects, or the lighting. Major research topics include

- Computational theory of shape recovery
- Model-based vision systems

Research also needs to be done to increase the flexibility of images that can be processed by including such capabilities as

- Identifying objects that overlap
- Accommodating for change in perspective
- Having fewer requirements on lighting conditions

Other research problems currently being explored include

- Representing knowledge about objects, particularly shape and spatial relationships
- Developing methods for reasoning about spatial relationships among objects
- Understanding the interaction between low-level information and high-level knowledge and expectations
- Interpreting stereo images, e.g., for range and motion

Relational Data Bases

An expert system that deals with objects in the world must have a model of the object that provides information required for reasoning about the object. The CAD data base augmented with additional data, such as data that explains the design choices that have been made, would provide this type of information. Research must be done to examine the various classes of expert systems to be used on the Space Station and ground support stations to determine the nature of the data base information required.

Improved user interfaces to access and modify data bases in a simple and natural manner are of great importance. Research in natural language understanding would be pertinent here.

Distributed Processing

The Space Station will be much more complex than any onboard distributed system of the past, and a number of important research and development issues must be addressed long before systems of this complexity are constructed. Among these are

- Develop and evaluate architecture design concepts based on careful study of projected requirements and possible implementations. New ground must be broken in developing integrated design concepts which include all of the types of processing required (from subsystem-embedded computers, to fault-tolerant control and autonomy processors, to special purpose front-end processors and high-speed data processors for support of experimental payloads). Current programs, such as the NASA High Speed Processor, are addressing portions of this problem, but a comprehensive examination of the total computing architecture is needed if systems are to be developed which can be used and evolve as new experiments and technology are introduced over a period of years.
- Define modular implementations which can use the same basic hardware and software components to implement a large portion of the various computing functions provided in the system. A well-defined architecture often uses a small set of powerful primitives to provide needed services while avoiding special cases which apply only to a few operations.
- Develop a small set of intercommunications structures with necessary fault-tolerance characteristics and which supply different communications services for different bandwidth applications. Hopefully, some degree of format compatibility can be obtained between the various structures, and they will be extensible as new devices are added to the network.
- Define the characteristics of virtual subsystems which are created when computers are embedded within.

Functional interfaces can be created which simplify commanding, system integration, testing, and the implementation of autonomy and fault-recovery features.

- Software executive concepts are needed to define both local and global executives for use within the various processors. How processes are assigned to processors, how they are scheduled, how they communicate, and how they share resource objects are some of the results needed here.
- Testbed experimentation is essential to understand onboard systems of the complexity of the Space Station, and it is required before prototype developments can be initiated. A testbed should not be started before a thorough architecture requirements definition is complete. It can then be used to verify and refine architectural concepts, and to develop software of the type that will be eventually used. Software executive concepts can be validated along with developing procedures for data storage and management, and communications strategies can be tested to validate the flow of data and control messages. It is important that the scope of a testbed be clearly defined and limited to proving the computing concepts to be used so that relevant results can be obtained in a timely fashion.

As the Space Station operates over a period of years, new technologies are expected to become available which will provide increases in performance by at least an order of magnitude. Examples are gallium arsenide signal processors, wafer-scale parallel processors, and gigabit bandwidth communication links. To develop a distributed processing architecture which can remain viable as technology changes is a serious challenge. Thus, planning for technology growth must be an important part of the architecture development. Part of the answer lies in hierarchic design. VHSIC technology should provide a level of performance which will remain adequate for many years in the core portions of the system which are dedicated to command, control, and autonomy functions. A modular approach should be taken for computational and communications services supplied for experimental payloads, since these will have computing demands which will grow with the supporting technology. Periodic equipment upgrades can be expected.

It is expected that ground-based processing will make use of high-performance local area networks that employ fault tolerance to achieve high availability and maintain the integrity of large data bases. Although this type of technology is being developed, and a commercial version running a distributed environment will soon become available, there are a number of research areas which should be pursued to improve this type of technology for Space Station applications. These research areas are

- Efficient implementation of atomic transactions to allow graceful recovery when a computer fails during a series of object updates.
- Developing techniques for maintaining data consistency when the network becomes partitioned due to a bus or processor failure. When a failed unit comes back on line, its disks may contain obsolete copies of replicated data.
- Hardware-assist techniques for improving performance. In order to maintain replicated copies of data, a large overhead in network traffic is required to maintain synchronization while providing object locking and atomic transactions. A large part of this overhead can be removed by providing specialized hardware support and specially tailored communications protocols (e.g., ring voting, lock caches, etc.).
- Techniques for providing full fault tolerance in a subset of the computations within the network (to be discussed below).

Fault-Tolerant Processing

For heterogeneous onboard distributed processing of the type expected on the Space Station, there will be a variety of different fault-tolerant requirements which will require the use of different fault-tolerant techniques for different types of functions for a satisfactory implementation.

To meet these varying requirements in a cost-effective fashion, it is necessary to develop a variety of fault-tolerant processing approaches for different parts of the system in a hierarchical fashion. Core control processes, which may be triplicated with voting, an expensive form of massive redundancy required for comprehensive fault tolerance, may be operated more efficiently in single self-checking processors, relying upon the core control elements to aid in recovery if a fault occurs. High-speed front-end processors used for processing high-rate sensor data will require high availability and should not be bothered by an occasional data error. Here, where processing demands are likely to greatly exceed available resources, it may be necessary to rely on external help from core processors both to detect faults and to effect recovery.

In addition to tolerance of computer faults, a similar hierarchy of autonomy mechanisms must be developed within the distributed system. Software means of detecting anomolies in subsystem operations, and strategies for dealing with system-wide effects of unexpected events, will be necessary.

Fault-tolerant processing and autonomy development will be critical components of all phases of system development through the computer architecture requirements definition, testbed development, and prototype construction. There are still many unanswered questions regarding the best way to implement these functions.

Fault tolerance should be an integral part of the architecture definition of the Space Station. Research into fault-tolerant techniques in heterogeneous multilayered systems is needed. Current reliability modeling techniques are incapable of dealing with systems of this complexity without making very gross assumptions about their structure and behavior. Techniques for verifying the fault-tolerant features of distributed hierarchic systems have yet to be developed. A combination of experimental fault insertion and analytic fault modeling can give insights about the effectiveness of autonomy and fault-tolerant mechanisms, but quantifying these performance levels is still an unsolved problem. Fault metrics need to be developed and appropriate standards applied to various processing, data transfer, and data storage functions.

Tolerance of software and design fault. The standard way in the past to deal with design and software faults has been to perform extensive testing in hope of eliminating them before launch. With systems as complex as the Space Station, it is unlikely that all such faults can be found and eliminated by testing. This is a very difficult and relatively new research area. Research which has been conducted in this area has taken two basic directions. The first, designated recovery blocks, uses modular software and performs acceptance tests on results as programs transition from one module to another. Alternate software modules are executed if anomalous behavior is detected. The second approach, designated N-version programming, operates multiple independently written copies of software and votes them at designated checkpoints to mask faults. When multiversion software is operated on different types of hardware, it may be possible also to circumvent both hardware and software design faults. Both of these approaches are expensive and will probably be reserved to highly critical applications.

Computer Technology

The current VHSIC program and other VLSI developments in industry are providing a technology base which can be exploited in the Space Station. These programs, which are heavily oriented to producing complex and fast devices, have centered on producing devices for specific applications. For example, the VHSIC chip sets are oriented toward specific military applications. Important research is needed on architectural issues of how the technology can be used for a broader class of problems in government and industry. It remains quite expensive to develop a custom circuit, so architectures are needed that use a small number of chip types which can be used for a wide range of applications. It is important to design the Space Station computing complex in such a way that a dozen or fewer custom chip types can be used as building blocks to interconnect the various processors and memories into a distributed system.

Multilevel architectures have been identified which are amenable to these highly modular implementations using a small set of custom "glue" chips. Standard chip types have been identified which allow construction of high-speed self-checking processors, with standard intercommunications interfaces. Other chips allow these single processors to be combined into very high-speed multiprocessors and additional port chips allow these multiprocessors to be connected into arrays of high performance multiprocessors. Building-block approaches of this type are needed to efficiently utilize VHSIC technology in the Space Station.

Because of the high degree of complexity of VHSIC chips, highly automated computer tools are needed to design them. This is an active area of research both in the government and in industry. The VHSIC program has stimulated development of design automation systems and has specified testability requirements for the chips produced. Many recent design systems allow different simulations to be carried out at various steps of the design process to detect errors before a chip is fabricated, but many errors can still slip through the design process. After a complex chip is fabricated, it is extremely difficult to test, because there are only a few connection pins to access thousands of logic circuits inside. Logic design techniques have been developed to improve testability of chips (such as IBM's Level Sensitive Scan Design and the inclusion of test circuits on-chip). The problem of chip testability is only partially solved, however, and this is another area in which research is badly needed.

As chips become more complex, their logic devices become much smaller, have lower operating margins, and operate at higher speeds. It is expected that transient errors will occur much more often, and internal fault-detection circuitry will need to be employed to detect and correct these faults before information damage occurs. It is also possible to include redundant circuits on a chip to effect recovery if a failure occurs inside or to increase production yields by circumventing non-functional logic when a device is produced. Both of these are active areas of research and need to continue. Products of this research can greatly improve reliability and performance in the Space Station.

Finally, it will be necessary to identify special-purpose devices needed within the Space Station (e.g., large bubble memories, signal processing logic, fiber optic communication port interfaces, optical storage devices) and to initiate the appropriate VLSI developments.

Software

There is considerable effort currently underway within DOD to address software issues, particularly in the STARS (Software Technology for Adaptable, Reliable Systems) program and the Software Engineering Institute at Carnegie-Mellon University. These activities are seeking improved methods for software production and maintenance for reliability and cost savings. NASA can benefit from these activities. An application from a space station autonomous system development could provide an excellent basis for applied research and testing of the software technology being developed under STARS.

Research in reliable software development and measurement techniques is needed, since autonomous systems require very high reliability in their control software. This work should include reliability assessment and software quality metrics. Methods for fault-tolerant software also need research to address both software able to operate within a faulty system as well as software built to tolerate design and implementation faults written into the software by mistake. Fault-tolerant software is complementary to hardware and system fault tolerance, and all these areas need research.

Programming language research should focus on automatic programming systems that help eliminate the potential for human error in developing new software. Automatic programming systems are still in the conceptual stage, and much research is needed before such systems can be used in production. The benefits of automatic programming systems will effect the initial development of more reliable software for the Space Station as well as the modifications to subsystems that will be required for the evolutionary growth station and the maintenance and enhancement of software existing on the Space Station. It is expected that NASA neither wants nor can afford to have programmers in space; hence, very high-level programming languages, application generators, and automatic programming systems will be necessary for the onboard or visiting crew.

Information Networks

Initial investigations have established three requirements for a space station information network: high performance, reliability/fault tolerance and extensibility/modularity. Massive communication capacity will be needed to support transmission of satellite images and multiple, real-time video channels. The communication workload will be heterogeneous, including voice, video, and data. The workload composition will not be static; not only will there be transient demands, but long-term demands will also evolve with the Space Station. Simply put, the Space Station needs high-capacity networks capable of adapting to changing, heterogeneous communication workloads. The integrity of the Space Station and the lives of its personnel will depend on continuous and reliable distribution of data for monitoring and control of the Station. As the Space Station changes and expands, the information system must evolve gracefully. A number of important technological areas must be addressed:

- A network mesh has multiple data communication links between network user sites or nodes, and has the physical appearance of a woven braid. This form of topology helps meet the requirements with the following features: (1) simultaneous adaptable data communication links offer dynamic and high-performance accommodation, and (2) alternate communication links provide a capability for fault-tolerant properties. This effort should be to research and characterize the architectural issues of the mesh form of network, including determining the appropriate type and form of protocols.

- Fiber optics with wavelengths division multiplexing (WDM) offers a reasonable means of achieving both high performance, by its inherent high bandwidth capacity, and extensibility, by utilizing a multiplicity of wavelengths available from semiconductor lasers. An example of the expandable capacity can be seen from a single wavelength system which is operating at 50 megabits. By adding four different wavelengths in the same common fiber, plus an optical multiplexer/demultiplexer, the system data rate can be increased to 200 megabits. This will provide an easy technique for providing additional data capacity to existing fibers. A greater data capacity is available by adding additional wavelengths to continue to expand the data handling capability of an information network. This effort should be to research and develop fiber optic WDM components and devices and WDM fiber optic networks.

- A network node forms the user interface into the network, controls user access to the network, provides adaptable multiple path data communications to/from other nodes, and provides for overall control of the network. With presently available technology, the use of optical fibers requires the use of optical to electrical (O/E) and E/O conversion at each node. Since these conversions require additional components and additional power and represent a potential system bottleneck, it seems there would be much to gain by constructing nodes which minimally would allow the passage of optical signals without O/E and E/O conversion and which should, ideally, perform many of the adaptable logic functions using optical rather than electronic techniques. The present state of optical technology suggests that a first generation optical node will be a hybrid opto-electronic device in which the switching will be optical but the logic and control signals will be electronic. Future generations of the node could be heavily optical as optical computation and logic capabilities improve.

- Video service will be required in the Space Station information systems to extend vision, to communicate data, to provide recreation, entertainment, and leisure for the crew and customers, and to record and store scenes and data, as well as for private communications, for inspection purposes, and for training simulation visual displays, graphical displays, computer terminal and other workstation displays, and caution and warning displays. In recent years there has been an explosion of technologies and methods applicable to digital video. It will be possible in the future to employ digital video from the source (digital video cameras), through the distribution network, and to the display (digital video monitors). The objective of this effort would be to identify and research an integrated and compatible set of equipment, procedures, and networking for a digital video system to service Space Station requirements.

- Networking Operating Systems: The state of the art in decentralized computers is succinctly stated by Jensen and Pleszkoch (1984).

  "Almost all work on 'distributed' systems in general and 'distribution'/ network operating systems in particular have been evolutionary to an extreme - most of the resource management concepts have been simple adaptives of centralized ones burdened by inappropriate and even counterproductive artifacts. The ineffectiveness of constructing airplanes which fly by flapping their wings was recognized early; but corresponding realizations about distributed systems have largely not yet taken place...."

  The need here, in order to support Teleoperator/Robotics for a manned Space Station, is the development of an advanced network O/S to provide decentralized management of resources, with functional singularity of purpose where needed, while acting with imperfect data and surviving failure through replication and recovery of information, and improving performance with concurrency.

INFRASTRUCTURE TO SUPPORT THE TECHNOLOGY BASE

In order to effectively support and coordinate the activities of the large number of people and organizations, the program should focus attention early on adequate infrastructure for the enterprise.

There should be three phases of activities. At the beginning of the program major emphasis should be placed on the consolidation of state-of-the-art technology to enable rapid capitalization and maximum resource sharing. A second phase should be designed to take advantage of early products of the program to enhance overall capabilities. A final phase should bring about a transition of the activities in the infrastructure to make them self-supporting. Any high initial investment in equipment, services, and training would be greatly rewarded with a most critical resource - trained personnel.

The infrastructure is categorized by specific activities to be performed. The most immediate need is availability of the products of technology so as to bootstrap the development process. Where appropriate, common processing equipment should be provided to selected participants in the first years and supplemented with more advanced equipment as it is developed in the program. Common access to high-performance networks should be provided to facilitate communication between sites and shared use of computing resources.

Next, a set of activities should address common access to services and tools that are the means of designing and building the elements of the new technology. These include rapid-prototyping implementation services providing foundry access to VLSI/VHSIC and GaAs fabrication lines as well as access to higher-level system implementation services. Computers are to be used extensively in the design and analysis of new systems, and these hardware and software tools should be shared between sites by exploiting the common hardware configurations, programming languages, and network communication facilities.

Additionally, specific activities should encourage collaboration between researchers through the development of interoperability standards. Strong interaction with the university community should be coupled with the use of the technology in the form of embedded instruction to accelerate the training and development of personnel.

The result would be a powerful expansion of the traditional concept of infrastructure. The program would produce not only an advanced technology base in the form of facilities, equipment, institutions, and knowledge, but also the methods for using it and accelerating its growth.

Capital Equipment

Hardware and software tools that could be common to a large number of research efforts should be developed early in the program to enable widespread use of advanced teleoperator and robot prototypes, symbolic computers, and communication systems in both laboratory and embedded applications.

No element of the infrastructure is as important as the need for widening the network connection among the various participants of the program. Beyond the obvious advantages of sharing resources and facilities, the network would be a means of promoting synergy between researchers located at different sites. This network should include other agencies (such as DOE, DOD, and NSF) in developing a common plan for leased wideband communication facilities to be made available by the common carriers. Existing networks, such as ARPANET, should be examined for suitability to satisfy this requirement.

Services

The physical construction of complex equipment is a difficult and time-consuming task, even when all the essential design details are understood. A set of services should be put in place that simplify this process, reduce cost, and provide rapid turnaround.

A service should be established to allow the rapid implementation of full-scale systems with the goal of enabling the assembly of complete prototype models from initial designs within a short period of time. Sources could be solicited for the design and manufacturing of "system kits" intended to facilitate interoperability and experimentation in new equipment designs. These standardized hardware and software environments would provide the physical means of easily integrating and assembling systems into predesigned modules using design frames for embedding unique custom designs as part of these systems.

Computer Tools for an Integrated System Development Environment

An advanced system development environment should be constructed as a framework for consolidation and integration of the design and performance analysis tools that are produced by this program. This environment would set the standards for tool development and facilitate the sharing of the products of this research between sites.

The new generation of hardware should be developed using new high-level tools that are built upon state-of-the-art research in VHSIC and VLSI design. These tools should be extended upward to enable system-level design, assembly, and test in a rapid system prototyping environment. It is here that the use of computing technology as a tool to create new computing technology is most obvious. In the functional design of a new machine architecture, its performance can be evaluated through emulation. It is expected that dedicated hardware emulation machines would be used to assess a number of architectures for which construction will be difficult or costly. Likewise, advanced hardware and software approaches to physical design aids would enable more rapid and robust system design.

An integrated rapid software and systems prototyping capability would be needed to support the development and application of multiprocessor systems. This capability should be developed by building upon advanced software and systems development environments such as Ada and common LISP and extending them to support multiprocessor targets. The major problems that need to be solved are to apply these architectures effectively and achieve the required performance and resource allocation for processor, memory, communication, and mass storage. In addition, the application system developers need support for using the new architectures in terms of the virtual machine interfaces that will be developed to manage resource allocation. The software and systems activities would produce the most generic software to support the application specific software. This includes programming languages, system software, and design and performance analysis tools for multiprocessor targets. As the technology matures, resource allocation will become more automatic and higher-level design environments for multiprocessor architectures should be developed.

Standards

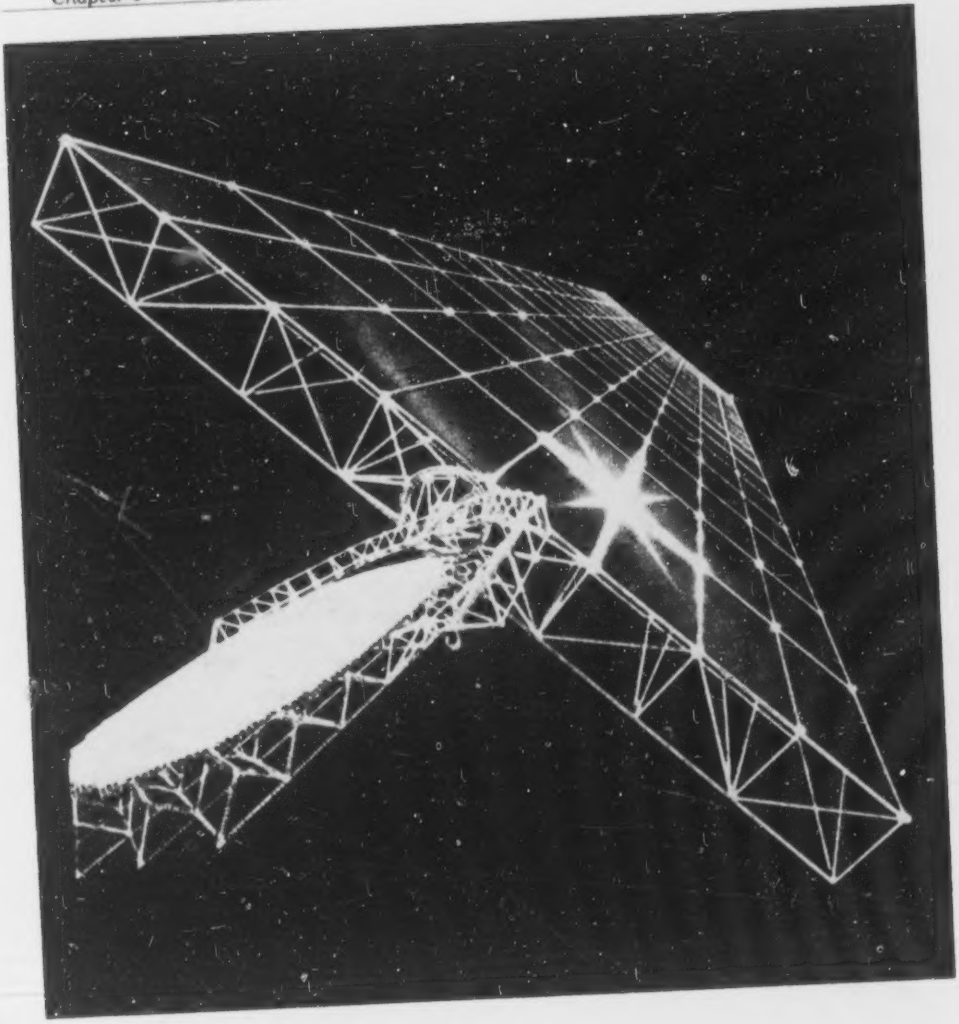
To integrate hardware and software to perform basic system functions, and then to integrate those functions into systems, will require interoperability research. A key ingredient will be the set of protocols that allow interaction between modules. It should be possible, for example, to access information in a knowledge base from a speech understanding system or to make available vision or natural language to a navigation system. Outputs from any of these should be available to AI-based simulation and display systems.

One should envision developing system interoperability protocols to the point where couplings of hardware, software, and peripheral devices may be selected and configured readily. This would include capabilities for teleoperation, robotics, speech input, vision, graphics, and a host of intelligent system tools including domain-independent expert system developmental tools and a LISP machine.

SELECTION OF TECHNOLOGY FOR RESEARCH AND DEVELOPMENT

Undoubtedly there will be a number of possible alternatives to choose from that could satisfy possible automation designs. The risk of being able to implement these alternatives along a prescribed schedule must be measured relative to the goals for the Space Station. Such an assessment should reveal the research and various development programs that would support the design. Specifically what technology do you push and when do you push it? The rationale for the technology selection should be clearly defined at the outset of the planning activities. The responsibility for developing the rationale should lie within the Space Station Program Office.

The goals for the Space Station are related both to maintaining a permanent presence in space and to enhancing our knowledge about building robotic and computer systems. The design philosophy should not only address the immediate and growth needs of the Space Station but it should also address the benefits to the U.S. economy in terrestrial applications. Wherever possible, automation areas should be identified that benefit both the Space Station and terrestrial application needs. This may mean, for example, that functions common to a large number of applications be clearly defined and assessed both in terms of prospects of successfully developing new technologies in a timely way. By clearly identifying these generic elements, it should be possible to define a technology development program that supports both the Space Station and terrestrial applications.



Chapter 7

TRANSFER OF TECHNOLOGY TO TERRESTRIAL APPLICATIONS

IMPORTANCE OF TECHNOLOGY TRANSFER

Congressional Directives

The Space Act of 1958 (PL85-568) requires that NASA transfer the results of its mission-related research and development to nonspace private and public sectors of U.S. society. In 1979 the Space Act was amended to direct NASA to assist in bioengineering research, development, and demonstration programs designed to alleviate and minimize the effects of disability. The Stevenson-Wydler Technology Innovation Act of 1980 (PL96-480) encouraged the exchange of scientific and technical personnel among universities, industry, and government. Its purpose was to stimulate improved utilization of federally funded technology by industry and by state and local governments.

In report 98-867 of the Committee of Conference to accompany bill HR 5713, which authorizes funding for the Space Station, it states, "*The conferees both intend and expect that the technologies of Space Station automation and robotics will be identified and developed not only to increase the efficiency of the station itself but also to enhance the nation's technical and scientific base leading to more productive industries here on Earth.*"

NASA thus has both an historical mandate for technology transfer and specific direction to see that automation and robotics technology developed for the Space Station be used to increase the productivity of U.S. industry.

Economic Rationale

Present economic indications point to the need for major changes in U.S. industry. These changes include an increase in technological innovation. The U.S. real GNP growth rate dropped from 4.2 percent, for the period 1960 to 1973, to 2.4 percent for the years 1974 through 1981. According to the present administration, this recent rate of economic growth is not sufficient to meet the nation's needs.

From 1960 to 1980, Japan and West Germany captured 30 percent of the U.S. market share of total world trade in manufactured goods. The U.S. balance of trade with Japan is particularly poor in specific high-technology industries.

The trend in productivity growth is not good. Since 1960, U.S. productivity has increased only 2 percent per year. In Japan, the annual rate of increase was 9 percent and in West Germany 3 percent.

Productivity is an important measure of economic capability because it reflects the ability of domestic producers to transform human and material resources into commercial goods and services.

Productivity is related to technology in that if the machine, information, and organization technologies are powerful and efficient, then the labor force will be more productive. According to Dr. George A. Keyworth, President Reagan's Science Advisor and Director, Office of Science and Technology Policy, "the real underlying problems we are facing" include "productivity, innovation, and the general health of our science and technology base." Further indication of a link between productivity and technology comes from the fact that R&D spending, as a proportion of GNP, has declined in association with the decline in productivity.

In light of the current economic situation, technology transfer is seen as a key ingredient in the effort to improve the vitality of the U.S. economy. With decreases in the rate of R&D spending, technology transfer takes on increased significance as a means of improving the technology component in U.S. industry. The purpose of technology transfer is to provide the general economy the advantages of a broader technological base without duplicating the R&D already done.

For any program of technology transfer to be successful, it must be economically viable. That is, the incremental benefit to society must be at least equal to the incremental cost to society. New technology transferred to industry can reduce production costs, improve product quality, or generate new products altogether. Productivity is increased, and industries become more competitive in world markets.

Some studies have attempted to quantify the economic benefits of technology transfer. Studies by Mathtech (1977) and Denver Research Institute (1979) applied a benefit/cost analysis to selected NASA technology transfer programs. The Mathtech report on nine projects shows an average benefit/cost ratio of 22. The Denver Research Institute report used a broader definition of costs and "lower bound" benefit estimates to arrive at an average benefit/cost ratio of 4. Even the more conservative report indicates that technology transfer, when done right, can have significant economic payoffs.

FACILITATION OF TECHNOLOGY TRANSFER

This section describes a plan for the transfer of NASA-developed automation and robotics technology to U.S. industry. The objective of this transfer effort is to increase productivity and competitiveness of U.S. industry in world markets. It should be emphasized that the plan does not describe new policies, but rather suggests how existing NASA policies and mechanisms can be used to transfer advanced automation and robotics technology.

In an effort to develop a technology transfer plan that would be both effective and efficient, two guidelines were established:

- One objective of the plan should be to establish a mechanism for consideration of industry's needs during the definition and preliminary design phases of the Space Station. At this stage, certain critical decisions will have a significant impact on the transferability of the technology to U.S. industry. For example, Space Station use of existing and evolving industry standards for data communication in automation could reduce the time and funds required for adaptation of the technology to an industrial environment.
- The plan should utilize NASA's established technology transfer mechanisms whenever possible. This approach would not only minimize the funds required for implementation of an automation and robotics technology transfer plan, but would avoid confusing industry by the existence of more than one NASA network with the objective of transferring aerospace technology to U.S. industry.

Considerations of Industry's Requirements

This section of the report discusses why one should consider the needs of industry during initial definition and design of the Space Station. Since Congress intends that automation and robotics be used not only to increase the efficiency of the Space Station, but also to lead to more productive industries on Earth, NASA needs to look beyond the Space Station when including automation and robotics in Space Station definition and design.

Congress has recognized the opportunity that the Space Station program offers to stimulate the advance of a range of automation and robotics technologies. Examples of such technologies include advanced vision sensors, control algorithms for robots with multiple types of sensors and manipulator systems with advanced multiple degrees of freedom. In the area of imbedded real-time computer control software, the Space Station program can lead to prototypes of the control software necessary to run the automation and robotic systems of the automated factories of the future. Examples of automatic factory software requiring significant development are real-time manufacturing resource control software, dynamic job shop scheduling software, and integrated computer-aided design, engineering, test, and manufacturing software. In some cases, these advances in both automation hardware and software will be direct enhancements of existing automated space vehicle technology such as sensor pointing systems, remote manipulators, and operation scheduling software.

Data communications and control. Part of defining the context in which this technology transfer will take place is establishing the state of automation and robotics technology in American industry today. At present, automation in American industry is characterized by a small number of very large corporations having various degrees of large, highly integrated, automated design and manufacturing systems. Medium sized companies exhibit smaller degrees of automation and are characterized by islands of automation in the sense of stand-alone automated machine tools and computer-based bookkeeping procedures. The penetration of automation and robotics into small manufacturers is very small indeed and is largely limited to microcomputer-based business management systems.

The current state of automation and robotics in American industry is characterized by the increasingly central role being played by the flexible manufacturing system (FMS) and the flexible manufacturing cell (FMC). Several years ago, much of the trade literature was full of the buzz phrase "automatic factory." The actual engineering integration and implementation of the totally automatic factory has proved to be extremely difficult and expensive. In a tactical retreat to less costly integrated automation, the FMS concept has evolved in American industry to address a somewhat smaller objective - that of a completely flexible production system for a finite family of products. By constraining the size, geometry, and materials of the products to be produced, the engineering problem is reduced to one of designing a manufacturing system that has to perform only a limited combination of operations on the raw materials to produce the desired end product. While flexible manufacturing systems are designed to produce an optimal, finite range of products, flexible manufacturing cells constrain themselves to smaller production requirements still. A good analogy to the concept of a flexible manufacturing cell would be the microgravity continuous flow electrophoresis system currently being tested by McDonnell Douglas onboard the Space Shuttle for production of a range of biological products. A single automated electrophoresis unit has the flexibility to separate a large number of different biological feed stocks into viable products, including blood cells, cell components, antigens, hormones, and proteins. In the same vein, the Space Station can be considered not so much as an automatic factory but as a flexible manufacturing system made up of many flexible manufacturing modules or cells. Typical examples of these cells would be the continuous flow electrophoresis production module; electronic materials (crystal) growing modules; metals, glasses, and ceramic fabrication modules; fluid and chemical production modules; and microsphere production modules. Just as in modern American manufacturing job shops, Space Station operations must schedule the jobs of each cell due to limited amounts of such resources as power, feedstock, and data communications. In short, the practical operating time and resource constraints of the flexible manufacturing system that is the Space Station are the same generic operating constraints that limit the productivity of the thousands of medium and small American companies every day. Providing commonly available, automated solutions to these generic real-time operating problems would have a profound impact on the productivity of American companies of all sizes. The automation and robotics technologies which have the greatest potential for solving these real-time operating problems and enhancing American productivity may not relate to hardware but rather to control algorithms and control models used to improve the productivity of operations.

Collaboration with American industry on Space Station technology spinoffs would be facilitated if NASA were to adopt the automation standards of industry where possible. These standards, specifically those related to automation, arise from a number of organizations including the Institute of Electrical and Electronics Engineers (IEEE), the Electronics Industries Association (EIA), the American National Standards Institute (ANSI), and others. For example, a major, current thrust by industry is in the area of automation data communications on the factory floor. American industry has a critical need for local area networks (LAN's) that allow a whole range of computers and computer-controlled equipment to intercommunicate on the factory floor. Similarly, a key element of the Space Station as a flexible manufacturing system may be an onboard local area network. Factory LAN's have architectures which are based on newly adopted standards. Two examples of these standards are the international standards organization Open Systems Interconnect (OSI) reference model for data communications and General Motors manufacturing automation protocol (MAP) reference model.

The international standards organization OSI model is rapidly becoming the worldwide standard for digital communications. As a result, companies are rushing to develop both hardware and software implementations under various levels of the OSI protocol. There is an emphasis on implementation of the OSI model in local area networks using the various IEEE-802 protocols, including the token-passing bus protocol and the token-passing ring protocol (figure 22).

As illustrated in figure 22, the IEEE-802 protocols relate to the bottom two layers of the model. Because of the nature of the layered model, the adoption of a particular standard at the physical and link levels does not restrict one's choices for the higher levels. Within each layer, functions exchange data according to the established protocols for that layer. Each layer draws upon a well-defined set of services provided by the layer below and provides a similarly well-defined set of services to the layer above. As long as these service interfaces are preserved, the internal operations within a layer are unconstrained; therefore, an entire layer may be removed and replaced if so dictated by changing user or technological requirements. This characteristic of the layered approach makes it a powerful tool in designing adaptable, evolutionary systems.

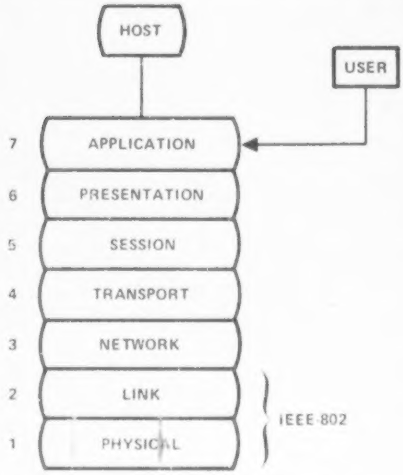


Figure 22.- Layered OSI model for data communications.

General Motors has adopted the IEEE-802 token-passing protocols for its MAP specification. According to General Motors' Ron Floyd, GM now has installed some 20,000 programmable controllers and 2,000 robots. If other computer-based control product devices are included, the number of intelligent devices installed in GM's manufacturing areas totals more than 40,000, with a projected 400- to 500-percent increase in the next 5 years. A severe problem exists for GM at present in that few of these 40,000 devices can talk to each other. To solve its problem, the company is attempting to convince control manufacturers to adopt the IEEE-802 data communications standards so that one form of computer-controlled equipment can talk to another, regardless of the original manufacturer.

There are those, however, who caution that LAN's may not be the best approach to automating a factory which has a very large number of devices (Taylor, 1984). They argue that network theory is based upon a telephone system model of communications, while factories operate according to a bulletin board system. That is, instead of flowing along a large number of two-way paths, factory information is posted so that all interested parties can read it from a common source. An alternative to the LAN approach has been proposed based upon a very fast fiber optic bus which turns the entire factory into a single address space. The appropriateness of such a model for the Space Station has yet to be fully explored.

The need to adopt standardized approaches in Space Station automation and robotics goes beyond data communications. Standards would also be considered for embedded control systems architectures for the robotics systems and devices that are proposed for the Space Station. An example of a consistent, logical control architecture for robotics systems is the National Bureau of Standards (NBS) model for hierarchical automatic factory control. The DOD is researching other embedded control system architectures.

The implementation of the NBS model will soon reach a point where it can be used as a prototype to a second generation system for automated flexible manufacturing system control as required for Space Station automation. American industry, on its own, is moving to adopt internally supported standards for the various generic functions of the automatic factory or flexible manufacturing systems. In order to satisfy Congress' wishes in the transfer of Space Station automation and robotic technologies, it behooves NASA to adopt, for the Space Station system and subsystem design and architecture, as many industry standards as will adequately meet the functional and performance requirements of the Space Station program. This will not only minimize costs by maximizing the use of off-the-shelf technology on the Space Station, but should expand the potential vendor pool for Space Station program subcontracts to a large new population of American industrial automation and control vendors, including developers of the latest state-of-the-art and real-time control products. It is possible that many of the standards which American industry has or will soon adopt will meet the vast majority of the Space Station's functional and performance requirements. To facilitate the transfer of automation and robotics technology, current and imminently pending industry automation standards will be considered for appropriate Space Station applications.

Software. Another aspect of the Space Station design which will have a beneficial impact upon the technology transfer effort is software standardization. A standard language for the Space Station helps avoid costly program revisions when the computing environment changes and makes it easier for someone who did not write the software to maintain it later on. In addition, if standards chosen for the Space Station are the same as those commonly used in industry, then software developed for the Space Station will tend to be compatible with computing environments elsewhere. If software on the Space Station will run on existing computer systems in industry, the chances of successful transfer are greatly enhanced. While much software will be specific to Space Station systems, there will be a considerable amount which has general applicability or could be modified to fit another application. Decision making systems for monitoring and control or software for robotic control are examples of Space Station software which could easily prove useful on Earth.

In common with all other user organizations, the Department of Defense has faced this same situation in terms of their so-called "embedded computers" in weapons systems. Because of the magnitude of their activities, they have developed their own standard language for their applications. The language, known as Ada, was developed by the Higher Order Language Working Group of DOD with help from a very large number of individuals and organizations throughout the world, such as industrial groups, technical organizations, and universities (Booch, 1983).

Adherence to the Ada standard is being promoted by the DOD-sponsored development of a compiler evaluation laboratory. The laboratory is establishing a validation suite of several thousand test programs which test not only that all the features of the language are implemented, but also that extensions have not been added. Before a vendor can state that it has an Ada compiler, the compiler and run-time system will have to successfully compile and execute the validation suite of programs.

In addition to the effort to build Ada compilers, there is a companion effort to produce a software development environment for Ada. The development system, called the Ada Programming System Environment, will include such things as syntax-driven editors, intelligent linkers and loaders, debugging aids, and other development tools.

The momentum behind Ada is considerable. DOD has dictated that Ada will be used for all its embedded real-time system applications, and a $20-million-per-year software research institute is planned to deal largely with Ada issues. By the time of IOC, the use of Ada should be widespread, not only within DOD, but throughout the rest of the world as well. Ada compilers will be available for all major processors, and a large effort will have been made to optimize its execution. For these reasons, Ada will be considered for systems implementation on the Space Station.

Some caution must be exercised, however, by keeping in mind what Ada was designed to do and what it was not designed to do. The designers of Ada desired to create an environment which would encourage good programming practices. By imposing a rather strict programming style, Ada offers considerable advantages for systems programmers in software teams developing and maintaining complex software. Some of the characteristics which make Ada effective in the realm for which it was designed, however, make it less suitable for other uses, such as a general research language for artificial intelligence. In a research environment, the programmer often does not initially have a clear understanding of how best to attack a problem. A language is needed which allows maximum expressive power and flexibility to handle the considerable redevelopment which occurs. Because it was designed to enforce a strict programming discipline rather than to provide maximum flexibility, Ada may be more appropriate as a target language for artificial intelligence programs rather than as a development language.

For artificial intelligence applications, people have traditionally chosen to use special languages designed for the handling of symbols, lists, and relations among objects. The two commonly used languages for these purposes are LISP and PROLOG. Since most existing AI software is written in one of these two languages, and since they are likely to remain the languages of choice for AI applications in the future, it seems advisable to adopt one of them for the Space Station. Of the two, LISP is far more prevalent in this country, while PROLOG has received acceptance in Europe and Japan. There is currently an effort to devise a standard version of LISP, called COMMON LISP, which will run on most of the present LISP machines. The choice of a language for AI applications on the Space Station should take into account the portability of the language for transfer to computing environments on Earth.

There is an additional need for languages which are easy for engineers or systems operators to use in developing and modifying operational programs for digital control. Such languages are called Problem Oriented Languages (POL's). They are usually written to include terms unique to the particular application involved. Thus, a POL for robot control would use such terms as grasp, pick up, release, etc.

These languages can proliferate greatly since they are usually so specialized. Standardization and transportability are preserved by translating the POL statements by means of a string processing language into the standard systems language, for example, Ada. A string processing language which could be used for this task is STAGE-2 or its commercial equivalent TILT. The string processing language matches statements of the POL to the corresponding subroutines or skeletons of the standard systems language as taken from a skeleton library and translates the statements into statements in the standard systems language.

Established NASA Technology Utilization Mechanisms

In 1962 NASA initiated a Technology Utilization Program to meet the technology transfer mandate of the 1958 Space Act. The program has evolved a nationwide network to accelerate and broaden the transfer of aerospace technology to other sectors of the economy. The program is administered by the Technology Utilization and Industry Affairs Division of the Office of Commercial Programs at NASA Headquarters. Technology Utilization Officers at each NASA Field Center coordinate the transfer activities involving that center's technology. Utilization of this established program for the transfer of Space Station automation and robotics technology will provide an immediate, cost-effective access to a network already transferring aerospace technology to U.S. industry. Components of the Technology Utilization program range from technical information systems to adaptive engineering programs. These activities and mechanisms by which they could be used to transfer Space Station automation and robotics technology are described below.

Publications are an important part of the program to inform potential users of the NASA technology available for transfer. *Tech Briefs* is published twice a year and provides information in each issue on more than 200 new concepts, devices, or processes developed by NASA. These technologies are grouped into chapters entitled Materials, Life Sciences, Machinery, Mechanics, Physical Sciences, Electronic Systems, Electronic Components and Circuits, and Fabrication Technology. Interested firms can obtain additional information on a specific topic by ordering a Technical Support Package. Industry utilization of this publication is illustrated by the 160,000 requests in 1981 for additional information on innovations described in *Tech Briefs*. Another publication useful to industry is the semiannual *NASA Patent Abstracts Bibliography*, which lists more than 3,500 NASA-patented inventions available for licensing. *Spinoff* is an annual publication which summarizes the status of NASA's mainline programs developing technologies of the future and describes a representative selection of spinoff products and processes derived from NASA technology. The addition of a chapter in *Tech Briefs* and *Spinoff* devoted to automation and robotics would be an effective mechanism for informing industry of NASA's new technology in these areas. To ensure distribution of these publications to the appropriate industries, the person at each field center designated to coordinate automation and robotics transfer operations would work with the publishing organizations to develop a mailing list.

Applications Centers were established by NASA to provide information retrieval services and technical assistance to clients in the public and private sectors. The network consists of seven Industrial Applications Centers (IAC's) and two State Technology Application Centers (STAC's). Through these centers, clients have access to more than 10 million documents, 2 million of which are in computer-accessible NASA data banks. The scientists, engineers, and computer retrieval specialists on the Application Center staff can identify relevant literature for the client and provide assistance in applying the information to the company's best advantage while charging only a nominal fee for the services. State Technology Applications Centers provide a similar service for state and local governments. Effective utilization of the aerospace technology data base can reduce industry's R&D costs and expedite innovation. The technical reports generated by the program to meet Space Station robotics and automation requirements would be included in the NASA literature bases accessed by the Application Centers.

A Computer Software Management and Information Center (COSMIC) is operated by NASA to assist industry and Government agencies in the utilization of computer programs developed by NASA. Many of these programs are directly applicable to secondary use with little or no modification, while others can be adapted for special purposes at a fraction of the cost of developing an entire program. For example, Magnavox reported a savings of 6 person-months in the development of a digital optical recorder. COSMIC, located at the University of Georgia, has a library of 1,500 programs which perform such tasks as structural analysis, design of fluid systems, electronic circuit design, and determination of building energy requirements. COSMIC publishes an annual index of available programs and assists customers in identifying programs that meet their needs. Total sales for 1981 were $750,000, and the trend has been one of rapid growth. Software developed in the Space Station automation and robotics program could be made available to industry through COSMIC.

The Corporate Associates Program was initiated in 1980 by NASA in conjunction with the American Institute of Aeronautics and Astronautics. The program involves a series of seminars that are held at NASA Field Centers and attended by executives and managers from many of the nation's largest nonaerospace companies. The seminars bring together high-level industry representatives with NASA scientists and engineers to discuss possible applications of aerospace technology in industry. Workshops could be a valuable mechanism for the active exchange of information between industry and NASA regarding their respective requirements and technologies in automation and robotics.

Applications Engineering Projects involve the collaboration of NASA, industry, and other government agencies for adapting aerospace technology to meet technical needs in manufacturing as well as medicine and rehabilitation. To meet the Congressional mandate of "widest practicable and appropriate dissemination," the goal of the applications engineering projects is for industry to participate in the project and market the successful solution. In this way, the solution is made available to all potential users. An example of a NASA applications engineering project that solved an important problem in manufacturing was the Ultrasonic Bolt Tension Monitor. When bolts are subjected to severe stresses and strains in pressure vessels, bridges, or power plants, over- or under-tightened bolts can fail, resulting in serious accidents and costly equipment damage. NASA technology in the nondestructive evaluation of materials resulted in the development of a bolt tension monitor appropriate for use in industry. The importance of this applications engineering project was recognized by the trade journal *Industrial Research and Development* in awarding an IR-100 award in 1981 for the development of this instrument.

The Technology Applications Team serves as an active transfer agent for NASA's technology transfer program. A major premise of this program is the active participation of industry, Federal and State agencies, and the user community. A technology transfer methodology based upon an active transfer agent serving as a personal interface has evolved from the realization that the passive dissemination of information on technology in itself seldom results in effective technology transfer. This point is illustrated by a quote from the U. S. Congress, 1976:

> *"The mere availability of information does not cause its transfer or use. Printed materials alone, even expertly prepared, cannot stimulate interpersonal relations, define a problem, answer related questions, involve consulting authorities, provide follow-through on problems or relate to other agencies."*

The role of the Technology Applications Team is to identify priority needs and aerospace technology that can meet those needs, then broker the participation of other Federal agencies and industry to develop this need/technology match to the point of commercial introduction. The methodology used by the Applications Team for active technology transfer involves three phases described below and outlined in a Work Breakdown Structure, table 6, prepared by the Technology Applications Team at Research Triangle Institute.

Identify commercialization opportunities. This phase involves the identification of significant technology requirements of industry and NASA technology that could be utilized to meet those requirements. The Applications Team works closely with individual manufacturers and industry associations to identify technology requirements. For example, the Applications Team has contacted over 50 trade associations

TABLE 6.- WORK BREAKDOWN STRUCTURE

Level 1	Level 2	Level 3	Level 4
Technology Transfer Program	A.0 Identify Commercialization Opportunities	A.1 Identify Technology Requirements	A.1.1 Conduct and Document Advisory Panel Meetings
			A.1.2 Interviews with Industry and Government Experts
			A.1.3 Literature Reviews on Technology Needs
			A.1.4 Technology and Industry Workshops
			A.1.5 NASA TU Program
			A.1.6 Identify Presently Used Technologies
			A.1.7 Preliminary Estimates of Impact
			A.1.8 Select Appropriate Technology Needs
		A.3 Identify NASA Technology	A.2.1 Search Aerospace Technology Data Base through IAC
			A.2.2 Prepare Problem Statements
			A.2.3 Distribute Problem Statements through TUO's
			A.2.4 Contract Field Center Scientists and Engineers
			A.2.5 Contract Program Office Managers
		A.4 Evaluate Potential Solutions Incorporating NASA Technology	A.3.1 Review with Problem Originators
			A.3.2 Review with Technical Experts
			A.3.3 Review with TUO and Field Center Scientists and Engineers
			A.3.4 Select Commercialization Opportunities and Obtain TUO Approval
	B.0 Screening	B.1 Patent Search, Waivers, Licensing	
		B.2 Estimate Impact of Commercialization	B.2.1 Develop Impact Model
			B.2.2 Estimate Production Cost
			B.2.3 Preliminary Market Study
			B.2.4 Document Other Benefits
			B.2.5 Document Impact
		B.3 Technical Feasibility	B.3.1 Technology Gaps
			B.3.2 Scientific and Technical Uncertainties
			B.3.3 Estimated Product and Process Performance
		B.4 Identify Potential Manufacturers	B.4.1 Advisory Panels
			B.4.2 Industry Associations
			B.4.3 Industry Data Base
			B.4.4 Contact Firms
		B.5 Identify Manufacturer Qualifications	B.5.1 Government Industry Cooperation
			B.5.2 Technological Resources
			B.5.3 Confidentiality
			B.5.4 Financial Resources
			B.5.5 Product Line
			B.5.6 Marketing and Distribution

TABLE 6.- Concluded.

Level 1	Level 2	Level 3	Level 4
		B.6 Sources of Cofunding for Applications Engineering	B.6.2 Federal Agencies
			B.6.1 Industry and Industry/ Associations
			B.6.3 Market Protection
			B.6.4 Venture Capitalists
	C.0 Develop Commercialization Strategies	C.3 Assist in Development of Applications Engineering Project Plan	C.3.1 End Item Functional Requirements
			C.3.3 Applications Engineering Project Statement of Work
			C.3.4 Cost Estimates
			C.3.2 Tests, Evaluation, and Data Collection Requirements
		C.5 Develop and Document Cofunding Plan	C.5.1 Identify Potential Sources of Cofunding in Industry and Government
			C.5.2 Document Cofunding Mechanisms
		C.1 Document FDA and Other Regulatory Agency Requirements that Apply	
		C.6 Document Potential Manufacturers and R, D, and E Organizations for Performing Applications Engineering	
		C.4 Document Options for Providing Market Protection to Firms Investing in Commercialization	C.4.1 Patents, Patent Waivers, and Licensing
			C.4.2 Confidentiality
			C.4.3 Product Introduction Lead Time
		C.2 Market Development Strategy	C.2.1 Product and Process Acceptance
			C.2.2 Distribution System
	D.0 Task and Project Liaison		
	E.0 Records Maintenance		

in the past year to identify opportunities for NASA technology transfer. These include organizations such as the Society for Manufacturing Engineers (SME) and its daughter organizations the Robotics Institute of America, the National Machine Tool Builders Association, the American National Standards Institute, and the National Electrical Manufacturers Association. These associations are currently emphasizing automation and robotics as a first priority for their members. These associations provide opportunities for NASA to address broad segments of U.S. industry. For example, SME is currently preparing or planning (1) a 1985 *Directory of Manufacturing Research Needed by Industry* for all members and other requesters, (2) a feature issue of *Manufacturing Engineering* on "Manufacturing for and in Space," and (3) an ad hoc committee on space manufacturing applications. The NASA Applications Team has been invited to participate in all of these activities.

The second activity in this phase is the identification of applicable NASA technology through several mechanisms including the distribution of Problem Statements to Technology Utilization Officers (TUO's) at each NASA center. Each TUO is responsible for distributing the Problem Statements to the appropriate NASA scientists and engineers and forwarding their solutions back to the Applications Team for review with the problem originator.

Participation by the Applications Team in automation and robotics advisory panel or review meetings, as well as presentations of developing NASA technology, could efficiently expedite technology transfer. Such participation would increase Applications Team awareness of NASA automation and robotics participants and technology and would allow more expeditious technology transfer.

Screening. A match between an industry need and a technology represents a commercialization opportunity. The Applications Team facilitates the screening of the opportunities to assess the technical and commercial feasibility of the proposed solution. Patent and licensing options must be reviewed by the Applications Team in preparation for commercialization discussions with potential manufacturers. The Applications Team discusses the potential project with Federal agencies, industry, and industry associations to determine their interest in participation and cofunding.

Develop Commercialization Strategies

The strategy for successful technology transfer must consider product development and marketing factors, device evaluation, regulatory agency impact, acceptance by the user community, and the identification of funding sources for all phases of the project. The Applications Team works closely with the NASA Field Center to develop an applications engineering project plan including milestones and budget for the engineering development project.

An important NASA requirement for proceeding with a technology transfer project is the allocation of substantial cofunding from the manufacturer and/or other Federal agencies. The Applications Team assists NASA in the development and implementation of a plan for obtaining these cofunding commitments. In addition, the Team will prepare a list of potential manufacturers and assist NASA in the preparation of a plan for the selection of a manufacturer.

The NASA Applications Team will serve as an important resource in NASA's efforts to expedite the transfer of Space Station automation and robotics technology to U.S. industry. The Team will work with the automation and robotics program to facilitate interaction with industry associations, manufacturers, and other Federal agencies through existing Applications Team networks and mechanisms. In addition, the Applications Team's technology transfer activities in medicine and rehabilitation will facilitate the identification of possible opportunities to transfer Space Station automation and robotics technology to these areas.

Automation and Robotics Technology Transfer: A Case Study

NASA efforts in the transfer of automation and robotics technology to improve American industrial productivity predates the current Space Station program. As part of the current NASA Technology Utilization (TU) program, a number of different automation and robotics technology transfers are in different stages of implementation. One good example of an automation and robotics technology transfer project is the robotic vision project at Johnson Space Center. This section describes this project's history as a case study to illustrate the active technology transfer methodology. This methodology consists of the following primary steps:

Identify Commercialization Opportunity

- Define the technology need
- Identify the applicable NASA technology

Screening

- Evaluate candidate solutions

Develop Commercialization Strategies

- Develop project plan
- Implement and monitor the project

The technology need for improved robotic vision was identified by the NASA Applications Team at the Research Triangle Institute. In robotic material handling applications, the robotic vision system is presented with a view of manufactured parts in random orientations and attitudes. The problem for the robotic vision system is to distinguish between unique parts and determine the attitude of a given part. Once this information has been determined, the robot's control computer plans a trajectory for picking up a part from the right direction. Most current robotic vision systems are based on the digital image processing of two-dimensional images captured with various electronic camera systems. Historically, these techniques have been impractically slow, although new algorithms and custom serial processing hardware are making the vision speeds sufficiently fast to make robotic material handling practical in the factory. Other industrial applications that could benefit from an improved robotic vision system include robotic assembly of electronics and automobiles and automated inspection. Arthur D. Little's Robotics Study Group estimates that the robotic market will grow from $250 million in 1983 to over $1 billion by 1987 with over half of the installations requiring vision capabilities. The Yankee Group of Boston has targeted general part inspection and identification as an even greater market for optical pattern recognition in a computer vision market they estimate to grow from $42 million in 1983 to more than $342 million in 1987.

NASA technology at Johnson Space Center was identified by the Technology Utilization Office and the Applications Team as a potential solution to the requirement for improved robotic vision. Many future NASA Shuttle and Space Station applications such as soft docking, on-orbit assembly and construction tasks, satellite retrieval, and station-keeping operations, have a need for an improved optical pattern recognition system. The heart of this type of system is a programmable mask and associated software for high-density storage and correlation of reference images. The Microwave and Laser Section of the Tracking and Communications Division of JSC has been responsible for the development of all optical pattern recognition devices for use in space applications. This group has been responsible for the development of programmable mask technology as part of the NASA-wide Optical Processing Working Group. A major thrust of this work has been in applications of real-time optical Fourier transform processing in optical correlators and pattern recognition systems. The techniques developed by this group and the experience gained in working with past generations of these devices are directly applicable to industrial uses of optical pattern recognition.

The potential solution was evaluated by industry and U. S. Army engineers from Redstone Arsenal who were also seeking improved robotic vision systems. Their enthusiastic reviews resulted in a meeting of Texas Instruments, the U. S. Army, the Applications Team, and NASA representatives at Johnson Space Center to discuss a collaborative project.

A project plan for the robotic vision project was developed and agreed upon by all the participants. This plan defines the project tasks, individual and organizational responsibilities, management plan, budget, and cofunding plan. The cofunding plan for the project is presented in the following table.

	FY85	FY86	FY87
NASA Technology Utilization	$ 50K	$ 115K	$ 50K
NASA OAST	$200K	$ 200K	$200K
U. S. Army	$170K	$ 250K	$250K
Texas Instruments	$625K	$1000K	$750K

The project plan was implemented in December 1984. The plan's milestones and budget will provide the basis for quarterly project monitoring.

POTENTIAL CONTRIBUTIONS TO INDUSTRY

If industry's needs are addressed in the Space Station design process and an effective program of technology transfer is pursued, what are some of the possible benefits to U.S. industry? In this section we look at some automation needs in today's industries and some of the anticipated advances in automation and robotics in the Space Station program and try to see what impact these new automation and robotics technologies might have on industry. The discussion is not intended to be exhaustive, but rather illustrative of some things which could reasonably be expected to happen.

Need for Advanced Automation in Industry

Automation and robotics are starting to make significant inroads into U.S. industry. By the end of this decade, General Motors expects to have as many as 20,000 industrial robots operating in its automotive assembly plants. In addition to General Motors, Ford expects to have about 10,000 and Chrysler about 5,000 industrial robots. Although these numbers represent the current growth in the market for industrial robots, they do not accurately reflect the potential demand for such advanced factory automation. Most of today's robots are being purchased to fill welding and spray-painting applications, which are only two of several major catagories of robotic applications. The main reason for their being so popular is the fact that the technologies needed to address them were the ones which matured first. Other applications, especially those involving assembly operations, require adaptive control technologies, which are still embryonic. Thus, the current state of the art in automation and robotics must undergo significant advancement before the majority of industrial applications for A&R can be satisfied.

One of the best examples of the basis for the need for adaptive control is small parts assembly and inspection. Most small batch assembly operations are done by human hands because, without adaptive control, industrial robots have to have the parts presented to them in a predetermined manner. Even with machine vision and tactile feedback, robots must be able to reason in order to understand what they see and feel and to deal with the real world. That is why most of the progress being made today in adaptive control remains in the laboratory and not in the factory.

There are many contributing factors to the continued growth in the demand for advanced factory automation and, therefore, for adaptive control. The two most important reasons are rising labor costs and the need for improved quality control. Rising labor costs, coupled with generally decreasing costs for electronic hardware, are making factory automation more cost effective. Improved quality control is one means of increasing productivity, which is necessary for competing with foreign manufacturers.

NASA's Role in Providing Advanced Automation

While the need for advanced automation technology in industry is evident, the means of satisfying the need are not certain. There needs to be a well-funded, interdisciplinary, coordinated R&D program in A&R. There is also a need for providing low-cost technology to small business, which cannot afford the kind of advanced technologies being purchased by large corporations and the military.

The requirements for advanced automation and robotics on the Space Station will provide NASA with the opportunity to assume a leadership role in automation and robotics development. NASA is in a better position to accelerate such advancement than is industry because of several advantages NASA has in its ways of supervising and directing such development work. NASA has the unique ability to bring together various aspects of industry in a cooperative manner and get them to work with each other and share technology. Because such cooperation means less duplication of work, the costs associated with a joint effort are lower than those associated with uncoordinated effort. Since communication between coordinated development teams decreases the time associated with technological achievements, the goals are reached sooner than would be met in a competitive industrial environment.

In order to meet the requirement for autonomy for the Space Station, advancements in several technologies will be necessary. Adaptive control is one such technology which will have to be significantly advanced. Intelligent, general-purpose robots could play an important role in achieving autonomy for the Space Station, and the major technological challenge in building such a robot does not concern hardware, but software. Robots have been demonstrated in laboratory settings equipped with stereo vision, tactile feedback, and even voice I/O. However, these laboratory models are not capable of the adaptive control required by factory applications, especially assembly operations. Also, very little research has been conducted using dual-arm robots and even less with an AI robot controller, planning the robot's moves and dealing with the unexpected. The use of CAD technology, including data bases containing parts design information, have yet to be fully exploited in A&R research and development, especially in teaching a robot about its environment and how to perform its tasks. In other words, the hardware is available to meet the challenge of Space Station A&R, but the software is severely lacking. Therefore, the greatest contribution to industry from NASA's A&R research and development effort is most likely to be advanced software and the knowledge of how to apply it in a cost-effective manner.

Adaptive control technology developed for an intelligent robot on the Space Station could be transferred to industries on Earth by using the established NASA technology transfer mechanisms. NASA publications could be utilized to announce the development of the technology. The Corporate Associates Program could sponsor seminars to present the technology to high-level industry representatives. Software could be made available through COSMIC. The Technology Applications Team could identify the commercial opportunities for adaptive control, perform a market analysis, and evaluate the feasibility of adapting the technology for use in industry. If appropriate, an applications engineering project would be undertaken to implement the transfer operation, thus ensuring the availability and usability of the technology for industry.

Impact on Industry

What would be the potential impact of adaptive control on industry? As mentioned earlier, one area where adaptive control would have immediate impact is small parts assembly and inspection. Since assembly applications constitute about one-third of the total potential applications for industrial robots, the impact of adaptive control could be extensive.

In a study performed by Neil Digeronimo of the Cleveland International Research Institute (CIRI), robotic sales were predicted for the year 2000 under two scenarios: (1) a significant NASA development effort in robotics and artificial intelligence begins in 1985 and continues through IOC; (2) no NASA effort occurs. Without NASA effort robotic sales in assembly and inspection operations were predicted to be \$2.1 billion and with NASA effort, \$2.9 billion, or an increase of 38 percent due to the NASA effort.

In addition to assembly applications, repair and service applications are likely to be affected by the availability of adaptive control While repair and service tasks would require the ultimate in advanced automation and robotics technology, adaptive control would be a key element in meeting the technological requirements. Since service and repair functions make up 80 percent of the tasks in U.S. industries which use hard automation, there is potentially a very large market for robots which can perform repair and service functions. If the United States could develop such robotic capability before our foreign competitors, we would have a great advantage in the world marketplace.

If, in addition to adaptive control, we assume other needed artificial intelligence methods become developed sufficiently to achieve complete autonomy in a space robot by the year 2000, what would be some potential impacts on industry? One effect would be to significantly reduce the time scale for achieving completely autonomous robotic systems. Perhaps the greatest potential gain from such a development would be the advantage U.S. industries could have in robotic repair and service applications.

Another effect, assuming the technology were made readily available to industry, would be a dramatic increase in U.S. sales of industrial robots. Under this assumption, Digeronimo projected that sales would double the original prediction by the year 2000.

There are many other automation and robotics technologies besides the ones mentioned thus far in this section which may be developed for the Space Station. The potential applications for these technologies in industry are many and varied. Rather than attempt to discuss all such technologies and their applications, table 7 is included here to present a more extensive (but still incomplete) list of potential technologies to be developed for the Space Station and their applications in industry. A technology checked off corresponding to a given application indicates a technology which is expected to be significant for that application. Other unchecked technologies may also be applied, but they are seen as being less essential for the application. Many existing technologies which are not listed would also be required for various applications.

TABLE 7.- POTENTIAL TECHNOLOGIES DEVELOPED FOR THE SPACE STATION AND THEIR APPLICATIONS

	Applications										
Potential Technologies	Assembly	Maintenance & Repair	Product/ Process/ Structure Inspection	Plant/ Facility Security	Factory Control	Transporting & Handling Toxic Materials	Pruning, Picking, & Cultivating Agricultural Crops	Medical Surgery	Computer Communications	Go-fer for Disabled	Fire Fighting
Hybrid Robot/ Teleoperator	X	X	X	X		X	X	X		X	X
Adaptive Control	X	X	X	X		X	X	X		X	X
Off-Line Robot Programming Through CAD/CAM Technology	X	X	X								
Tactile Sensors (Arrays, Force Feedback)	X	X	X	X			X	X		X	
Advanced Machine Vision (3D-Scene Analysis)	X	X	X	X			X			X	X
Mobile Robot Guidance/Navigation		X		X		X	X			X	X
Advanced Planning for Robotics	X	X	X	X		X	X			X	X
Dual Arm Robotics	X	X				X				X	X
Dextrous Manipulator	X	X	X				X	X		X	
Robot Application Modeling by Visual Simulation	X	X				X	X	X			X
Diagnostic Expert System		X	X	X	X						X
Distributed Computing		X			X				X		
Advanced Data Storage Technology		X	X	X	X				X		
Intelligent Man/ Machine Interfaces	X	X	X	X		X		X		X	X
Intelligent Remote Sensor Technology		X	X	X	X						X
Energy Management/ Advanced Process Control Technology					X						
Advanced Fault-Tolerant Disciplines		X			X				X		

Chapter 8

COMMERCIALIZATION ACTIVITIES ON THE SPACE STATION

In this chapter we discuss the importance of developing the commercial opportunities of space, what NASA's policy is toward commercial activity in space, the special opportunities afforded by the Space Station, and how advanced automation and robotics on the Space Station will facilitate commercial ventures in space. All statements of NASA policy in this chapter are taken from the recently published *NASA Commercial Space Policy* (NASA, 1984a) and are a restatement of existing policy.

IMPORTANCE OF SPACE COMMERCIALIZATION

The call to pursue the commercial opportunities of space has been voiced repeatedly over the past few years by a number of Government and scientific sources. Here are some of the statements which have been issued.

"The United States Government will provide a climate conducive to expanded private sector investment and involvement in civil space activities...."

- President Ronald Reagan
National Space Policy
July 4, 1982

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"We should establish a policy which would encourage commercialization of space technology to the maximum extent feasible."

- Committee on Science and Technology
U.S. House of Representatives Report
April 15, 1983

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"The Committee is fully supportive of efforts by the private sector to invest and seek commercial opportunities in space."

- Committee on Commerce, Science and Transportation
U.S. Senate
Report May 16, 1983

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"The extent to which past investment in space technology contributes to our future economic well-being and national growth will depend in large measure on policies and actions taken in a spirit of collaboration by the Federal Government and industry.

"Unless the public and private sector join to develop the opportunities presented by new space technologies and unless entrepreneurial forces are engaged more fully, the United States will fall behind in the contest for leadership in space and the economic rewards associated with that position."

- National Academy of Public Administration
May 1983 Report

In mid-1983 NASA formed a task force for the purpose of examining the opportunities for and impediments to commercial activities in space. Their conclusions were

- Commercial activities in space by private enterprise should be expanded now if our nation is to retain and improve its leadership in science and technology, its high living standards, and its advantage in international trade.

- **Natural and bureaucratic barriers inhibiting the commercialization of space need to be and can be lessened or removed through joint actions by the Government and private enterprises.**

- **With firm resolve and the commitment of reasonable resources over a number of years, Government and private enterprise working together can turn space into a realm of immense benefit for our nation.**

- **A positive NASA Commercial Space Policy should be implemented to expedite the expansion of self-sustaining profit-earning tax-paying jobs-providing commercial space activities.**

NASA's thrust into the future is taking a new turn: NASA is inviting free enterprise to participate in space. NASA is encouraging industries and other private entities to finance and conduct business in space.

Private investment in space is called "space commercialization." Commercial projects would aim at developing profitable products and services. Envisioned are industries turning out useful goods for sale to consumers and industrial customers on Earth.

Stimulating the commercialization of space will give new impetus and importance to traditional space efforts. The rewards can be immense.

NASA has accumulated a long and proud history of working closely and productively with private enterprises. Sometimes likened to a tower on three pedestals, NASA space programs have been based on participation and contributions by a trio of segments in our society - Government, industry, and academic institutions.

Since its earliest days, NASA has employed industries and universities as contractors. NASA was the customer. The other partners were the suppliers. Project Apollo, history's largest engineering project, was an example of this three-way partnership.

Since 1962 NASA has provided launch services for commercial communications satellites. Beginning in 1972, NASA entered into "partnership" arrangements with private firms for the commercial use of space. Now, the nature and character of NASA's relationship with private enterprise is changing still more. To persuade private investors to become involved in new space endeavors, NASA must be responsive to the needs and wants of these investors.

NASA must assure these investors of reliable and dependable roundtrip transportation for their projects between Earth and orbit. NASA must also help assure the availability of suitable work places for industries in orbit.

Space commercialization may turn out to be less headline-catching than were the landings by men on the Moon in the late 1960's and early 1970's. But major endeavors by private enterprise in space are likely to make the 1980's and 1990's just as exciting and spectacular.

Moreover, space commercialization can have profound impact on the future of our nation. We already know from our experiences with highly profitable, privately owned communications satellites that free enterprise in space works well. New leaps in technology which may emerge from private initiatives in space could have major implications for the national economy, individual living standards and life styles, industrial activities and jobs, and international trade. Outer space appears destined to become a major arena of international technological and commercial rivalry. The United States cannot ignore the competition from abroad if it wants to retain its preeminence. NASA, as a lead agency for advanced technology, must accept the challenge. NASA must reshape and reorient itself to accommodate and spearhead the new National needs and goals.

NASA COMMERCIAL SPACE POLICY

In response to the need for formulating an enlightened and aggressive approach to space commercialization, representatives from NASA Headquarters and Field Centers have drawn up the NASA Commercial Space Policy. These representatives looked at the commercial possibilities in space and how NASA can encourage more private industrial ventures in space. To supplement their perspective, the NASA representatives sought and received advice from experts in industry and universities as well as other outside specialists.

Goals and Principles

The primary goal of NASA's Commercial Space Policy is to encourage and stimulate free enterprise in space.

Private investments in space, in turn, are expected to (a) yield important economic advantages, (b) advance science and technology, (c) help maintain U.S. space leadership, and (d) enhance the nation's competitive position in international trade, thereby improving the U. S. balance of payments.

Implementation of the NASA Commercial Space Policy is to be guided by these five principles:

(1) The Government should reach out to and establish new links with the private sector.

NASA will expand its traditional links with the aerospace industry and the science community to include relationships with major nonaerospace firms and new entrepreneurial ventures, as well as with the financial and academic communities.

(2) Regardless of the Government's view of a project's feasibility, it should not impede private efforts to undertake commercial space ventures.

If the private sector is willing to make the necessary investment, the feasibility of a project should be determined by the marketplace and the creativity of the entrepreneur rather than the Government's opinion of its viability.

(3) If the private sector can operate a space venture more efficiently than can the Government, then such commercialization should be encouraged.

When developing new public space programs, the Government should actively consider the view of, and the potential effect on, the private sector.

(4) The Government should invest in high-leverage research and space facilities which encourage private investment. However, the Government should not expend tax dollars for endeavors the private sector is willing to underwrite.

This will provide at least two benefits. First it will enable NASA to concentrate a greater percentage of its resources on advancing the technological state of the art in areas where the investment is too great for the private sector. Second, it will engage the private sector's applications and marketing skills for getting space benefits to the people.

(5) When a significant Government contribution to a commercial endeavor is requested, two requirements must be met. First, the private sector must have significant capital at risk, and second, there must be significant potential benefits for the nation.

In appraising the potential benefits from and determining appropriate Government contributions to commercial space proposals, NASA will utilize an equitable, consistent review process.

A possible exception to these principles would be a commercial venture intended to replace a service or displace a NASA R&D program and/or technology development program of paramount public importance now provided by the Government. In that case, the Government might require additional prerequisites before commercialization.

Implementation

In implementing this policy, NASA will take an active role in supporting commercial space ventures in the following categories, listed in order of importance:

- New commercial high-technology space ventures

- New commercial applications of existing space technology
- Commercial ventures resulting from the transfer of existing space programs to the private sector

NASA will implement initiatives to reduce the technical, financial, and institutional risks associated with doing business in space.

To reduce technical risks, NASA will

Support research aimed at commercial applications opportunities; ease access to NASA experimental facilities; establish scheduled flight opportunities for commercial payloads; expand the availability of space technology information of commercial interest; and support the development of facilities necessary for commercial use of space.

To reduce financial risks, NASA will

Continue to offer reduced-rate space transportation for high-technology space endeavors; assist in integrating commercial equipment with the Shuttle; provide seed funding to stimulate commercial space ventures; and, under certain circumstances, purchase commercial space products and services and offer some exclusivity.

To reduce institutional risks, NASA will

Speed integration of commercial payloads into the Orbiter; shorten proposal evaluation time for NASA/private sector Joint Endeavor proposals; establish procedures to encourage development of space hardware and services with private capital instead of Government funds; and introduce new institutional approaches for strengthening NASA's support of private investment in space.

The Commercial Development Division has been established within the Office of Commercial Programs at NASA Headquarters to coordinate commercial space matters. NASA Field Centers will participate in both the development and operational phases of the program. The program will identify space commercialization opportunities and industries suitable for developing these opportunities and will establish the means to make potential space investors aware of these opportunities.

COMMERCIALIZATION OPPORTUNITIES ON THE SPACE STATION

The Space Station will provide an unparalleled opportunity for space commercialization. For the first time there will be a permanent station in space with both manned and unmanned elements. The Space Transportation System will make the Space Station accessible for supplying raw materials and equipment and for returning finished products.

Advantages Offered by the Space Station

A variety of unique conditions will be provided by the Space Station for commercial use. These include, at least

- Microgravity
- High vacuum
- Isolation from disturbance and contamination
- An abundance of cosmic ray primaries
- A synoptic view of Earth

The advantages of these conditions can be considerable, depending on the application. For example, General Electric has examined the possibility of growing crystals of gallium arsenide by an electroepitaxial process in space, and has estimated that the yield for the highest level of quality could be increased from only about 1 percent on Earth to as much as 70 percent in space, resulting in substantial cost savings.

The Space Station will provide commercial firms with the opportunity to carry out a variety of endeavors in space. These include

- Experimental work of many kinds
- Manufacturing processes; e.g., crystal growth and production of ultrapure pharmaceuticals

- Assembly of large-scale space structures
- Satellite assembly, repair, and maintenance

Other applications are possible in the more distant future, such as using the Space Station as a base for lunar mining or planetary exploration and colonization.

Some specific applications which have been considered for Space Station include

- Stereoscopic imaging system for Earth observation
- Hydroponic plant growth
- Material processing, such as
  - Gallium arsenide processing
  - Mercury cadmium telluride processing
  - Magnetophoresis separation
- Solar optical telescope
- Electrophoretic separation of biologicals
- Microelectronics chip production
- Large structure fabrication

Enhancing Commercial Opportunities

Commercialization opportunities on the Space Station can be enhanced in a number of ways. One way is by making the Space Station an accessible laboratory for the development and testing of new products for a large base of users (i.e., small, as well as large, industries). Therefore, it is desirable to establish a mechanism within NASA whereby a small business with limited financial resources could utilize the Space Station. At one time, the Advanced Applications Flight Experiment (AAFE) office at LaRC provided support for small business to propose and conduct system flight experiments. Possibly, this concept could be resurrected and applied to promote wider use of the Space Station. Two elements are critical to making such a program work. First, submittals should be accepted on a regular schedule, at least yearly, so that companies can plan ahead and be assured their proposals will be considered. Secondly, there should be designated points of contact within NASA that these companies can approach at any time.

As an example, consider a small business concern that wants to test an innovative man/machine interface using the various workstations and advanced systems onboard the Space Station. Results of the system test might indicate that the product is superior to existing versions. In such a case NASA would adopt the technology for its own applications, while the business would be allowed to market the product for use in terrestrial applications, thereby effecting a bidirectional transfer of technology.

Another way to encourage participation of small businesses is through the Small Business Innovative Research Program (SBIR). In this program proposals from businesses are solicited in a large number of space-related areas. If separate sections in the Announcement of Opportunity were devoted to artificial intelligence and to robotics/teleoperations with sufficient funding to support a large number of research projects, more small businesses would be able to try out innovative ideas in automation and robotics. Such new ideas are essential to advancing the state of the art to meet Space Station requirements beyond IOC.

Another means of enhancing commercial opportunities on the Space Station is by simplifying and speeding up the process of integrating commercial payloads. Several steps could be taken to accomplish this goal.

- Assigning a payload support group to work in partnership with the private investor to assist in all integration activities
- Standardizing and maximizing the number of locations on the Space Station to which commercial payloads could be integrated
- Assuring the availability of pallets and other equipment carriers and pressurized modules for simplified interfaces

- Allowing the commercial partner to establish its own acceptable payload risk levels

ROLE OF AUTOMATION IN SPACE COMMERCIALIZATION

Automation is a key element in the successful commercialization of space. In a general sense, automation will make the Space Station a better environment for support of commercial ventures. Automation can help reduce the costs of operating the Space Station, which will in turn affect the rates the Government will have to charge private industry for using Space Station facilities. Automation will increase productivity on the Space Station, making commercial manufacturing operations more productive. The safety of the crew and the station itself will be enhanced by automated fault diagnosis and recovery systems. Fault-tolerant, highly reliable computing facilities will ensure effective collection of experimental data and support for manufacturing processes.

Specific applications will rely on automation for different reasons. Many applications would not be feasible in space without automation. Automation allows manufacturing or experimental activities to occur without constant attendance by humans. Automation can make possible operations which might otherwise be dangerous or undesirable for humans to perform. Some manufacturing processes involve handling hazardous materials or produce toxic products. Growing gallium arsenide crystals is one example. Certain manufacturing processes involve very precise, repetitive cutting, shaping, or welding operations which are more effectively performed by machines than by humans. Automation will be necessary to support any experiments or Earth-viewing operations which require the use of platforms distant from the Space Station itself. Expert systems for process control will be used to control manufacturing operations.

Flexible, intelligent teleoperation and robotics systems will provide support to a variety of commercial activities in space. They can be used for materials handling in manufacturing. They will be essential for any large-scale construction in space. A study by TRW (TRW, 1984) details the need for teleoperations and robotics in satellite servicing. Flexible, automated systems can be used to service a variety of spacecraft, economically and effectively. A general-purpose robot could also be used to retrieve film or otherwise service an Earth-viewing satellite in geosynchronous orbit. Remote manipulators will be used to deploy and retrieve experiment packages at the Space Station.

The commercial utilization of space is a high-priority item in our overall space program. The Space Station will provide unique opportunities to realize this goal. The automation technology being developed for the Space Station will play a key role in making space commercialization a success.

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ACRONYMS AND ABBREVIATIONS

A&R - Automation and Robotics
AC - Alternating Current
ACS - Attitude Control System
ADH - Advanced Development Hardware
AEC - Atomic Energy Commission
AI - Artificial Intelligence
ANSI - American National Standards Institute
AOS - Aquisition of Signal
ARC - Ames Research Center
ASCII - American Standard Code for Information Interchange
ASR - Automatic Speech Recognition
ATAC - Advanced Technology Advisory Committee
ATP - Authority to Proceed
BIBB - Bus Interface Building Block
BIU - Bus Interface Unit
C&T - Communications and Tracking
CAD - Computer Aided Design
CAE - Computer Aided Engineering
CAI - Computer Aided Instruction
CAM - Computer Aided Manufacturing
CCTV - Closed Circuit Television
CDR - Critical Design Review
CI - Customer Integration
CMDS - Commands
CMG - Control Moment Gyro
CSD - Contract Start Date

DARPA - Defense Advanced Research Projects Agency

DBMS - Data Base Management System

DDT&E - Design, Development, Test, and Evaluation

DMS - Data Management System

DOC - Department Of Commerce

DOD - Department Of Defense

DOE - Department Of Energy

DOF - Degrees Of Freedom

DR - Data Requirement

DTO - Detailed Test Objective

ECLSS - Environmental Control and Life Support System

EMI - Electromagnetic Interference

EMS - Engineering Master Schedule

EMU - Extravehicular Mobility Unit

EOS - Earth Observing System

EPS - Electrical Power System

ESS - Energy Storage Subsystem

EV - Extravehicular

EVA - Extravehicular Activity

FOC - Full Operational Capability

GaAs - Gallium Arsenide

GEO - Geosynchronous Earth Orbit

GFE - Government Furnished Equipment

GFP - Government Furnished Property

GN&C - Guidance, Navigation, and Control

GPS - Global Positioning System

GSE - Ground Support Equipment

GSFC - Goddard Space Flight Center
HMF - Health Maintenance Facility
ICD - Interface Control Document
IDMS - Information and Data Management System
IEEE - Institute of Electrical and Electronic Engineers
IGES - Initial Graphic Exchange Specification
IOC - Initial Operational Capability
IPS - Instrument Pointing System
IRD - Interface Requirements Document
IRR - Initial Requirements Review
ISR - Interim System Review
IV - Intravehicular
IVA - Intravehicular Activity
JPL - Jet Propulsion Laboratory
JSC - Johnson Space Center
KBPS - Kilobits Per Second
KIPS - Knowledge Information Processing Systems
KSC - Kennedy Space Center
LaRC - Langley Research Center
LeRC - Lewis Research Center
LIPS - Logical Inferences Per Second
LOS - Loss Of Signal
MBPS - Megabits Per Second
MDB - Master Data Base
MMU - Manned Maneuvering Unit
MPAC - Multipurpose Application Consoles
MS - Margin of Safety

MSFC - Marshall Space Flight Center
NASA - National Aeronautics and Space Administration
NHB - NASA Handbook
NMI - NASA Management Instruction
NSF - National Science Foundation
NSTS - National Space Transportation System
OAST - NASA Office of Aeronautics and Space Technology
OEA - NASA Office of External Affairs
OMV - Orbital Maneuvering Vehicle
ORU - Orbital Replaceable Unit
OSC - NASA Office of Space Commercialization
OSF - NASA Office of Space Flight
OSI - Operator/System Interface
OSS - NASA Office of Space Station
OSSA - NASA Office of Space Science And Applications
OSTDS - NASA Office of Space Tracking And Data Systems
OSTP - White House Office of Science And Technology Policy
OTV - Orbital Transfer Vehicle
PC - Personal Computer
PDR - Preliminary Design Review
PGS - Power Generation Subsystem
PL - Public Law
PMAD - Power Management and Distribution
POCC - Payload Operations Control Center
PRCB - Program Requirements Change Board
PWR - Space Station Power Subsystem
R&D - Research and Development

RCB - Requirements Change Board
RCS - Reaction Control System
RF - Radio Frequency
RFI - Radio Frequency Interference
RFP - Request For Proposal
RMS - Remote Manipulator System
ROV - Remotely Operated Vehicle
RTG - Radioisotope Thermoelectric Generators
SAR - Synthetic Aperture Radar
SDE - Software Development Environment
SDR - System Design Review
SE&I - Systems Engineering and Integration
SEB - Source Evaluation Board
SEC - Station Executive Controller
SI - International System of Units
SIR - Systems Integration Review
SOW - Statement of Work
SR&QA - Safety, Reliability, and Quality Assurance
SRR - System Requirements Review
SSDMS - Space Station Data Management System
SSDS - Space Station Data Systems
SSIS - Space Station Information System
SSP - Space Station Program
SSPE - Space Station Program Element
SSWP - Space Station Work Package
STD - Standard
STS - Space Transportation System

TBD - To Be Determined

TCS - Thermal Control System

TDASS - Tracking and Data Acquisition Satellite System

TDRSS - Tracking and Data Relay Satellite System

TLM - Telemetry

U.S. - United States

VHSIC - Very High Speed Integrated Circuits

VLSI - Very Large Scale Integration

WBS - Work Breakdown Structure

WP - Work Package

GLOSSARY

[This glossary was obtained from Gevarter, 1983.]

A

Activation Mechanism: The situation required to invoke a procedure - usually a match of the system state to the preconditions required to exercise a production rule.

AI Handbook: The Handbook of Artificial Intelligence, E.A. Feigenbaum, A. Barr and P.R. Cohen (Eds.). Published by W. Kaufmann, Los Altos, CA in 1981 and 1982. This important project was supported by DARPA and NIH.

Algorithm: A procedure for solving a problem in a finite number of steps.

AND/OR Graph: A generalized representation for problems reduction situations and two person games. A tree-like structure with two types of nodes. Those for which several successors of a node have to be accomplished (or considered) are AND nodes. Those for which only one of several of the node successors are necessary are OR nodes. (In about half the literature the labeling of AND and OR nodes is reversed from this definition.)

Antecedent: The left-hand side of a production rule. The pattern needed to make the rule applicable.

Argument Form: A reasoning procedure in logic.

ARPANET: A network of computers and computational resources used by the U.S. AI community and sponsored by DARPA (Defense Advance Research Projects Agency).

Artificial Intelligence (AI): A discipline devoted to developing and applying computational approaches to intelligent behavior. Also referred to as machine intelligence or heuristic programming.

Artificial Intelligence (AI) Approach: An approach that has its emphasis on symbolic processes for representing and manipulating knowledge in a problem solving mode.

Atom: An individual. A proposition in logic that cannot be broken down into other propositions. An indivisible element.

Autonomous: A system capable of independent action.

B

Backtracking: Returning (usually due to depth-first search failure) to an earlier point in a search space. Also a name given to depth-first backward reasoning.

Backward Chaining: A form of reasoning starting with a goal and recursively chaining backwards to its antecedent goals or states by applying applicable operators until an appropriate earlier state is reached or the system backtracks. This is a form of depth-first search. When the application of operators changes a single goal or state into multiple goals or states, the approach is referred to as problem reduction.

Blackboard Approach: A problem solving approach whereby the various system elements communicate with each other via a common working data storage called the blackboard.

Blind Search: An ordered approach that does not rely on knowledge for searching for a solution.

Blocks World: A small artificial world, consisting of blocks and pyramids, used to develop ideas in computer vision, robotics, and natural language interfaces.

Bottom-Up Control Structure: A problem solving approach that employs forward reasoning from current or initial conditions. Also referred to as an event-driven or data-driven control structure.

Breadth-First Search: An approach in which, starting with the root node, the nodes in the search tree are generated and examined level by level (before proceeding deeper). This approach is guaranteed to find an optimal solution if it exists.

C

Clause: A syntactic construction containing a subject and a predicate and forming part of a statement in logic or part of a sentence in a grammar.

Cognition: An intellectual process by which knowledge is gained about perceptions or ideas.

Combinatorial Explosion: The rapid growth of possibilities as the search space expands. If each branch point (decision point) has an average of n branches, the search space tends to expand as nd, as depth of search (d) increases.

Common Sense: The ability to act appropriately in everyday situations based on one's lifetime accumulation of experiential knowledge.

Common Sense Reasoning: Low-level reasoning based on a wealth of experience.

Compile: The act of translating a computer program written in a high-level language (such as LISP) into the machine language which controls the basic operations of the computer.

Computational Logic: A science designed to make use of computers in logic calculus.

Computer Architecture: The manner in which various computational elements are interconnected to achieve a computational function.

Computer Graphics: Visual representations generated by a computer (usually observed on a monitoring screen).

Computer Network: An interconnected set of communicating computers.

Computer Vision (Computational or Machine Vision): Perception by a computer, based on visual sensory input, in which a symbolic description is developed of a scene depicted in an image. It is often a knowledge-based expectation-guided process that uses models to interpret sensory data. Used somewhat synonymously with image understanding and scene analysis.

Conceptual Dependency: An approach to natural language understanding in which sentences are translated into basic concepts expressed as a small set of semantic primatives.

Conflict Resolution: Selecting a procedure from a conflict set of applicable competing procedures or rules.

Conflict Set: The set of rules which matches some data or pattern in the global data base.

Conjunct: One of several subproblems. Each of the component formulas in a logical conjunction.

Conjunction: A problem composed of several subproblems. A logical formula built by connecting other formulas by logical AND's.

Connectives: Operators (e.g., AND, OR) connecting statements in logic so that the truth-value of the composite is determined by the truth-value of the components.

Consequent: The right side of a production rule. The result of applying a procedure.

Constraint Propagation: A method for limiting search by requiring that certain constraints be satisified. It can also be viewed as a mechanism for moving information between subproblems.

Context: The set of circumstances or facts that define a particular situation, event, etc. The portion of the situation that remains the same when an operator is applied in a problem solving situation.

Control Structure: Reasoning strategy. The strategy for manipulating the domain knowledge to arrive at a problem solution.

D

Data Base: An organized collection of data about some subject.

Data Base Management System: A computer system for the storage and retrieval of information about some domain.

Data-Driven: A forward reasoning, bottom-up, problem solving approach.

Data Structure: The form in which data is stored in a computer.

Debugging: Correcting errors in a plan.

DEC: Digital Equipment Company.

Declarative Knowledge Representation: Representation of facts and assertions.

Deduction: A process of reasoning in which the conclusion follows from the premises given.

Default Value: A value to be used when the actual value is unknown.

Depth-First Search: A search that proceeds from the root node to one of the successor nodes and then to one of that node's successor nodes, etc., until a solution is reached or the search is forced to backtrack.

Difference Reduction: "Means-Ends" analysis. An approach to problem solving that tries to solve a problem by iteratively applying operators that will reduce the difference between the current state and the goal state.

Directed Graph: A knowledge representation structure consisting of nodes (representing, for example, objects) and directed connecting arcs (labeled edges, representing, for example, relations).

Disproving: An attempt to prove the impossibility of a hypothesized conclusion (theorem) or goal.

Domain: The problem area of interest; e.g., bacterial infections, prospecting, and VLSI design.

E

Editor: A software tool to aid in modifying a software program.

Embed: To write a computer language on top of (embedded in) another computer language (such as LISP).

Emulate: To perform like another system.

Equivalent: Has the same truth value (in logic).

Evaluation Function: A function (usually heuristic) used to evaluate the merit of the various paths emanating from a node in a search tree.

Event-Driven: A forward chaining, problem solving approach based on the current problem status.

Expectation-Driven: Processing approaches that proceed by trying to confirm models, situations, states, or concepts anticipated by the system.

Expert System: A computer program that uses knowledge and reasoning techniques to solve problems normally requiring the abilities of human experts.

F

Fault Diagnosis: Determining the trouble source in an electromechanical system.

Fifth Generation Computer: A non-Von Neumann, intelligent, parallel processing form of computer now being pursued by Japan.

First Order Predicate Logic: A popular form of logic used by the AI community for representing knowledge and performing logical inference. First Order Predicate Logic permits assertions to be made about variables in a proposition.

Forward Chaining: Event-driven or data-driven reasoning.

Frame: A data structure for representing stereotyped objects or situations. A frame has slots to be filled for objects and relations appropriate to the situation.

FRANZLISP: The dialect of LISP developed at the University of California, Berkeley.

Functional Application: The generic task or function performed in an application.

Fuzzy Set: A generalization of set theory that allows for various degrees of set membership, rather than all or none.

G

Garbage Collection: A technique for recycling computer memory cells no longer in use.

General Problem Solver (GPS): The first problem solver (1957) to separate its problem solving methods from knowledge of the specific task being considered. The GPS problem solving approach employed was "means-ends analysis."

Generate and Test: A common form of state space search based on reasoning by elimination. The system generates possible solutions and the tester prunes those solutions that fail to meet appropriate criteria.

Global Data Base: Complete data base describing the specific problem, its status, and that of the solution process.

Goal Driven: A problem solving approach that works backward from the goal.

Goal Regression: A technique for constructing a plan by solving one conjunctive subgoal at a time, checking to see that each solution does not interfere with the other subgoals that have already been achieved. If interferences occur, the offending subgoal is moved to an earlier noninterfering point in the sequence of subgoal accomplishments.

Graph: A set of nodes connected by arcs.

H

Heuristic Search Techniques: Graph searching methods that use heuristic knowledge about the domain to help focus the search. They operate by generating and testing intermediate states along potential solution paths.

Heuristics: Rules of thumb or empirical knowledge used to help guide a problem solution.

Hierarchial Planning: A planning approach in which first a high-level plan is formulated considering only the important (or major) aspects. Then the major steps of the plan are refined into more detailed subplans.

Hierarchy: A system of things ranked one above the other.

Higher Order Language (HOL): A computer language (such as FORTRAN or LISP) requiring fewer statements than machine language and usually substantially easier to use and read.

Horn Clause: A set of statements joined by logical AND's. Used in PROLOG.

I

Identity: Two propositions (in logic) that have the same truth value.

Image Understanding (IU): Visual perception by a computer employing geometric modeling and the AI techniques of knowledge representation and cognitive processing to develop scene interpretations from image data. IU has dealt extensively with three-dimensional objects.

Implies: A connective in logic that indicates that if the first statement is true, the statement following is also true.

Individual: A nonvariable element (or atom) in logic that cannot be broken down further.

Infer: To derive by reasoning. To conclude or judge from premises or evidence.

Inference: The process of reaching a conclusion based on an initial set of propositions, the truths of which are known or assumed.

Inference Engine: Another name given to the control structure of an AI problem solver in which the control is separate from the knowledge.

Instantiation: Replacing a variable by an instance (an individual) that satisfies the system (or satisfies the statement in which the variable appears).

Intelligence: The degree to which an individual can successfully respond to new situations or problems. It is based on the individual's knowledge level and the ability to appropriately manipulate and reformulate that knowledge (and incoming data) as required by the situation or problem.

Intelligent Assistant: An AI computer program (usually an expert system) that aids a person in the performance of a task.

Interactive Environment: A computational system in which the user interacts (dialogues) with the system (in real time) during the process of developing or running a computer program.

Interface: The system by which the user interacts with the computer. In general, the junction between two components.

INTERLISP: A dialect of LISP (used at Stanford University) developed at BBN and XEROX-PARC.

Invoke: To place into action (usually by satisfying a precondition).

K

Knowledge Base: AI data bases that are not merely files of uniform content, but are collections of facts, inferences, and procedures, corresponding to the types of information needed for problem solution.

Knowledge Base Management: Management of a knowledge base in terms of storing, accessing, and reasoning with the knowledge.

Knowledge Engineering: The AI approach focusing on the use of knowledge (e.g., as in expert systems) to solve problems.

Knowledge Representation (KR): The form of the data structure used to organize the knowledge required for a problem.

Knowledge Source: An expert system component that deals with a specific area or activity.

L

Leaf: A terminal node in a tree representation.

Least Commitment: A technique for coordinating decision making with the availability of information, so that problem solving decisions are not made arbitrarily or prematurely, but are postponed until there is enough information.

List: A sequence of zero or more elements enclosed in a pair of parentheses, where each element is either an atom (an indivisible element) or a list.

List Processing Language (LISP): The basic AI programming language.

Logical Operation: Execution of a single computer instruction.

Logical Representation: Knowledge representation by a collection of logical formulas (usually in First Order Predicate Logic) that provide a partial description of the world.

M

MACLISP: A dialect of LISP developed at M.I.T.

Means-Ends Analysis: A problem solving approach (used by GPS) in which problem solving operators are chosen in an iterative fashion to reduce the difference between the current problem solving state and the goal state.

Meta-Rule: A higher level rule used to reason about lower level rules.

Microcode: A computer program at the basic machine level.

Model Driven: A top-down approach to problem solving in which the inferences to be verified are based on the domain model used by the problem solver.

Modus Ponens: A mathematical form of argument in deductive logic. It has the form: If A is true, then B is true.
A is true.
Therefore, B is true.

N

Natural Deduction: Informal reasoning.

Natural Language Interface (NLI): A system for communicating with a computer by using a natural language.

Natural Language Processing (NLP): Processing of natural language (e.g., English) by a computer to facilitate communication with the computer or for other purposes such as language translation.

Natural Language Understanding (NLU): Response by a computer based on the meaning of a natural language input.

Negate: To change a proposition into its opposite.

Node: A point (representing such aspects as the system state or an object) in a graph connected to other points in the graph by arcs (usually representing relations).

Nonmonotonic Logic: A logic in which results are subject to revision as more information is gathered.

O

Object-Oriented Programming: A programming approach focused on objects which communicate by messege passing. An object is considered to be a package of information and descriptions of procedures that can manipulate that information.

Operators: Procedures or generalized actions that can be used for changing situations.

P

Parallel Processing: Simultaneous processing, as opposed to the sequential processing in a conventional (Von Neumann) type of computer architecture.

Path: A particular track through a state graph.

Pattern Directed Invocation: The activation of procedures by matching their antecedent parts to patterns present in the global data base (the system status).

Pattern Matching: Matching patterns in a statement or image against patterns in a global data base, templates, or models.

Pattern Recognition: The process of classifying data into predetermined categories.

Perception: The process of classifying data into predetermined categories.

Personal AI Computer: New, small, interactive, stand-alone computers for use by an AI researcher in developing AI programs. Usually specifically designed to run an AI language such as LISP.

Plan: A sequence of actions to transform an initial situation into a situation satisfying the goal conditions.

Portability: The ease with which a computer program developed in one programming environment can be transferred to another.

Predicate: That part of a proposition that makes an assertion (e.g., states a relation or attribute) about individuals.

Predicate Logic: A modification of Propositional Logic to allow the use of variables and functions or variables.

Prefix Notation: A list representation (used in LISP programming) in which the connective, function, or predicate is given before the arguments.

Premise: A first proposition on which subsequent reasoning rests.

Problem Reduction: A problem solving approach in which operators are used to change a single problem into several subproblems (which are usually easier to solve).

Problem Solving: A procedure using a control strategy to apply operators to a situation to try to achieve a goal.

Problem State: The condition of the problem at a particular instant.

Procedural Knowledge Representation: A representation of knowledge about the world by a set of procedures - small programs that know how to do specific things.

Production Rule: A modular knowledge structure representing a single chunk of knowledge, usually in If-Then or Antecedent-Consequent form. Popular in Expert Systems.

Programming Environment: The total programming setup that includes the interface, the languages, the editors, and other programming tools.

Programming in Logic (PROLOG): A logic-oriented AI language developed in France and popular in Europe and Japan.

Property List: A knowledge representation technique by which the state of the world is described by objects in the world via lists of their pertinent properties.

Proposition: A statement (in logic) that can be true or false.

Propositional Logic: An elementary logic that uses argument forms to deduce the truth or falsehood of a new proposition from known propositions.

Prototype: An initial model or system that is used as a base for constructing future models or systems.

Pseudoreduction: An approach to solving the difficult problem case where multiple goals must be satisfied simultaneously. Plans are found to achieve each goal independently and then integrated using the knowledge of how plan segments can be intertwined without destroying their important effects.

R

Recursive Operations: Operations defined in terms of themselves.

Relaxation Approach: An iterative problem solving approach in which initial conditions are propagated utilizing constraints until all goal conditions are adequately satisfied.

Relevant Backtracking (Dependency-Directed or Nonchronological Backtracking): Backtracking (during a search) not to the most recent choice point, but to the most relevant choice point.

Resolution: A general, automatic, syntactic method for determining if a hypothesized conclusion (theorem) follows from a given set of premises (axioms).

Root Node: The initial (apex) node in a tree representation.

Rule-Interpreter: The control structure for a production rule system.

S

Satisficing: Developing a satisfactory, but not necessarily optimum, solution.

Scheduling: Developing a time sequence of things to be done.

Scripts: Frame-like structures for representing sequences of events.

Search Space: The implicit graph representing all the possible states of the system which may have to be searched to find a solution. In many cases the search space is infinite. The term search space is also used for non-state-space representations.

Semantic: Of or relating to meaning.

Semantic Network: A knowledge representation for describing the properties and relations of objects, events, concepts, situations, or actions by a directed graph consisting of nodes and labeled edges (arcs connecting nodes).

Semantic Primitives: Basic conceptual units in which concepts, ideas, or events can be represented.

S-Expression: A symbolic expression. In LISP, a sequence of zero or more atoms or S-expressions enclosed in parentheses.

Slot: An element in a frame representation to be filled with designated information about the particular situation.

Software: A computer program.

Solution Path: A successful path through a search space.

Speech Recognition: Recognition by a computer (primarily by pattern matching) of spoken words or sentences.

Speech Synthesis: Developing spoken speech from text or other representations.

Speech Understanding: Speech perception by a computer.

SRI Vision Module: An important object recognition, inspection, orientation, and location research vision system developed at SRI. This system converted the scene into a binary image and extracted the calculated needed vision parameters in real time, as it sequentially scanned the image line by line.

State Graph: A graph in which the nodes represent the system state and the connecting arcs represent the operators which can be used to transform the state from which the arcs emanate to the state at which they arrive.

Stereotyped Situation: A generic, recurrent situation such as "eating at a restaurant" or "driving to work."

Subgoals: Goals that must be achieved to achieve the original goal.

Subplan: A plan to solve a portion of the problem.

Subproblems: The set of secondary problems that must be solved to solve the original problem.

Syllogism: A deductive argument in logic whose conclusion is supported by two premises.

Symbolic: Relating to the substitution of abstract representations (symbols) for concrete objects.

Syntax: The order or arrangement (e.g., the grammar of a language).

T

Terminal Node (Leaf Node): The final node emanating from a branch in a tree or graph representation.

Theorem: A proposition, or statement, to be proved based on a given set of premises.

Theorem Proving: A problem solving approach in which a hypothesized conclusion (theorem) is validated using deductive logic.

Time-Sharing: A computer environment in which multiple users can use the computer virtually simultaneously via a program that time-allocates the use of computer resources among the users in a near-optimum manner.

Top-Down Approach: An approach to problem solving that is goal-directed or expectation-guided based on models or other knowledge. Sometimes referred to as "Hypothesize and Test."

Top-Down Logic: A problem solving approach used in production systems, where production rules are employed to find a solution path by chaining backwards from the goal.

Tree Structure: A graph in which one node, the root, has no predecessor node, and all other nodes have exactly one predecessor. For a state space representation, the tree starts with a root node (representing the initial problem situation). Each of the new states that can be produced from this initial state by application of a single operator is represented by a successor node of the root node. Each successor node branches in a similar way until no further states can be generated or a solution is reached. Operators are represented by the directed arcs from the nodes to their successor nodes.

Truth Maintenance: A method of keeping track of beliefs (and their justifications) developed during problem solving so that if contradictions occur, the incorrect beliefs or lines of reasoning, and all conclusions resulting from them, can be retracted.

Truth Value: One of the two possible values - True or False - associated with a proposition in logic.

U

Unification: The name for the procedure for carrying out instantiations. In unification, the attempt is to find substitutions for variables that will make two atoms identical.

V

Variable: A quantity or function that may assume any given value or set of values.

Von Neumann Architecture: The current standard computer architecture that uses sequential processing.

W

World Knowledge: Knowledge about the world (or domain of interest).

World Model: A representation of the current situation.

SPACE SYSTEMS TERMINOLOGY

Any field develops a certain amount of specialized terminology or "jargon" in order to convey complicated ideas in a terse manner. Descriptions of space vehicles and systems are often replete with such jargon. The writers of this report have tried, as much as possible, to avoid specialized terminology. Some of the terms used by the specialists are very helpful, however, and are difficult to avoid without cumbersome substitutions. The following definitions and examples will aid in understanding some of the terms used in this report.

Co-orbiting: Said of a satellite orbiting in an orbit close to and readily accessible to the Space Station orbit.

Fail-safe/fail-operational: Said of a design approach for a spacecraft component in which a failure of the component will result in a condition that is operational if possible or at least safe.

Fault-tolerant: A feature of a (computer) system which allows some level of operation to continue even after a fault has occurred.

Hooks: Provisions made in computer software upon which future capability can be built or "hung." This can save expensive restructuring of the software when additional capability is needed. This practice is analogous to leaving a slot in a concert program which can be filled when the details of the performer and the selection to be played have been worked out.

Human/Machine Interface: The devices, programs, and procedures by which a human interacts with a machine.

Model: A representation, frequently done analytically with a computer, of some physical situation which aids in understanding. For example, an analytical representation of the response of a proposed robot to external stimuli could aid in the design of the robot.

Phases B, C, D: Stages in implementing a space project; respectively, (B) preliminary design and definition, (C) detailed design, and (D) construction.

Platform: A flight element of the Space Station Program which carries out special tasks in a separate orbit from that of the station and which is serviced in some way by the station.

Proximity Sensor: A sensing device that detects when an object comes within a specified distance of the device.

Retro-Fit: The retroactive modification of a system or device after it has been put in service.

Scars: Provisions made in hardware to accommodate future features. This is analogous to reinforcing the end of a driveway when one knows that a garage is to be erected later on. In a Space Station example, provisions could be made for pads to which an inspection robot would later be attached.

Teleoperation: The execution of physical tasks by a manipulating device under human control.

Telepresence: The concept of remotely controlled manipulation in which the manipulators at the worksite have the dexterity to perform normal human functions and the operator at the control site has sensory feedback sufficient to provide the feeling of being present at the remote site where the action is taking place.

Trade (or Trade-Off Study): An assessment of the optimum combination of elements or design to achieve a desired goal. For example, increasing the precision of a thrust control device might increase the weight of the device but save on fuel consumption and thus reduce overall weight.

Transparent: Said of a change (to a computer program) not visible or readily apparent to the primary user.

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16. Abstract

In response to Public Law 98-371, dated July 18, 1984, the NASA Advanced Technology Advisory Committee has studied automation and robotics for use in the Space Station and prepared this report to the House and Senate Committees on Appropriations. The report is divided into two volumes:

The Executive Overview, Volume I, presents the major findings of the study and recommends to NASA principles for advancing automation and robotics technologies for the benefit of the Space Station and of the U.S. Economy in general.

The Technical Report, Volume II this document, provides background information on automation and robotics technologies and their potential and documents:

The relevant aspects of Space Station design;

Representative examples of automation and robotics; applications

The state of the technology and advances needed; and

Considerations for technology transfer to U.S. industry and for space commercialization

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SUBCOMMITTEE RECESS

Senator GARN. The subcommittee will stand in recess until Wednesday, March 27, at 10 a.m., in SD-124, at which time we will hear from the Treasury Office of Revenue Sharing, New York City Loan Program, Consumer Products Safety Commission, Office of Science and Technology Policy, and Council on Environmental Quality.

[Whereupon, at 12:18 p.m. Thursday, March 14, the subcommittee was recessed to reconvene at 10 a.m. Wednesday, March 27.]

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT-INDEPENDENT AGENCIES APPROPRIATIONS FOR FISCAL YEAR 1986

TUESDAY, MARCH 27, 1985

U.S. SENATE,
SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10 a.m. in room SD–124, Dirksen Senate Office Building, Hon. James Abdnor presiding.

Present: Senators Abdnor, Proxmire, Leahy, and Domenici.

EXECUTIVE OFFICE OF THE PRESIDENT

OFFICE OF SCIENCE AND TECHNOLOGY POLICY

STATEMENT OF DR. G.A. KEYWORTH II, DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

ACCOMPANIED BY JERRY D. JENNINGS, EXECUTIVE DIRECTOR

OPENING REMARKS

Senator ABDNOR. The Subcommittee on HUD and Independent Agencies will come to order.

As you can see from our nameplates, I am Senator Abdnor. I will be filling in for our chairman of the committee today, who could not be with us. I have agreed to pinch-hit.

We have the Office of Science and Technology Policy with us; we have the Department of Treasury, the Office of Revenue Sharing; we have the Consumer Product Safety Commission, and the Council on Environmental Quality. We are going to be moving right along. I am sure you all have statements, and I can assure you that your entire statements will be made a part of the record. I just ask you to summarize and we will go from there.

The Office of Science and Technology Policy, which is before us first, was created by the National Science and Technology Police, Organization, and Priorities Act of 1976. The Office was designed to provide advice to the President on scientific and technological considerations in areas of national and international concern and advises the National Security Council. In addition, the Office provides general leadership and coordination of the research and development programs of the

Federal Government and assists the Office of Management and Budget with reviews of proposed budgets for Federal R&D programs. The Office also advises Congress on the executive branch's views regarding science and technology policy and, in this regard, has proven quite useful to this subcommittee.

Our budget request for fiscal year 1986 is for $2,091,000 and 15 full-time permanent positions. This represents a decrease of $123,000 over the estimated fiscal year 1985 level.

I am sure we can put that into the record. I said nothing that you don't know much better than I do, gentlemen, and you can proceed any way you care.

FUTURE COURSE CHARTED

Dr. KEYWORTH. Thank you, Senator Abdnor.

The start of a new administration and a new Congress is an appropriate time to take stock and chart a course for coming years. Many of our efforts are going to be concerned with critical choices we have to make in three areas. One is national security—how to create a more stable world and, specifically, how to reduce the presence of nuclear weapons. A second is how we in America can assure our economic progress in the face of rapidly growing competition in the world's industrial markets. And the third is how we can bring Government spending under better control and reduce the deficit that intrudes so rudely on our plans for the future.

Senator, I think you will agree that our enviable lead in science is an important thread that runs through all of those issues—because science and technology are tools to forge our own destiny. They are our leverage on the future.

Fortunately, we go into the 1986 budget deliberations with our science and technology enterprise significantly strengthened over that of not many years ago. The growth of 55 percent in support for basic research over the course of these past two Congresses is restoring momentum to what is one of this country's greatest assets—our scientific enterprise.

In addition, and equally important, this high priority assigned to science by the Federal Government has elicited comparable high priority in the private sector for using that science. Industry has been increasing its rate of investment in research and development even faster than Government has, and in doing so it has also forged productive new partnerships with universities.

PREEMINENCE IN SCIENCE

But here I have to interpose a cloud into that sunny picture. Our science and technology present may be brighter than it has been in years, but a shining future is anything but guaranteed. Our leadership in science is fragile—extremely fragile. That should concern us deeply, because science plays the same role for technology as does a foundation for a house. Neither structures nor modern industries can exist without those bases of support. And today we depend—far more than most people realize—on our preeminence in science to enable us to exploit technology and maintain our economic and national security.

RESEARCH AND DEVELOPMENT PROGRAMS

Senator, we are challenged this year to balance two dominant priorities. One is to permit investment in our future by reducing Federal spending. The other is to assure a strong national science and technology base. The budget being presented to the Congress does both.

Funding obligations for R&D will total $60 billion in fiscal year 1986; of that, $20 billion will support non-DOD R&D, and $8 billion will support basic research. Funds obligated for non-DOD research and development will decrease slightly from 1985 to 1986, and funds for basic research will increase slightly above the freeze level. Within those proposed budgets I have no doubt whatsoever that we can conduct extremely effective R&D programs.

After 4 years of near-historic funding increases, there is now plenty of momentum in the system to maintain healthy progress. Moreover, as a matter of practicality, actual outlays for basic research would rise by nearly 5 percent next year, which should even permit a little real growth. In addition, because we have deliberately postponed the start of construction for major new research facilities for 1 year, we will be able to maintain strong funding for ongoing research programs. In light of the increased Federal support since 1981, there will be no threat to the health of U.S. science. I would even say that, after such rapid growth, sharing in the overall Federal austerity may well stimulate sharper delineation of priorities for science.

GROWTH OF S&T FUNDING

I strongly support the necessity of slowing the growth of science and technology funding in the short term as part of the response to the deficit. But at the same time I won't hide my concern about the vitality of U.S. science over the longer term and about its continued attraction for the best young minds. Even the most optimistic forecasters warn us of several years of lean funding until we get the deficit to a level where it doesn't dominate Federal budgeting.

As I said, we are in good shape for 1986. Our real challenges will come in fiscal years 1987 and 1988, when we simply will have to find ways to ensure our ability to pursue—and pursue vigorously—new avenues of research. Progress in science won't stagnate, and it won't wait for us. Other countries, facing equally trying times, are renewing their support of basic science. And they are doing it in emulation of our own miracle. The last thing we want to do is lose sight of our own successes and what stimulated them. So we will have to be prepared to make hard choices to fund new starts for high-priority research facilities under whatever fiscal scenario we face in coming years. What will be at stake will be the scientific leadership that we can't afford to compromise.

Let me introduce a practical point here. As we focus upon fueling the engine of technology, there are two logical buttons to push: The quality or the quantity button. Losers push the quantity button, and the technology engine sputters. Winners push the quality button, and the engine revs up. If we keep our eye on supporting quality, sufficient talent will follow to maintain our technological and scientific lead.

I raise this issue of quality as opposed to quantity because constraints on resources in coming years will continually challenge us to make wise decisions to preserve our leadership. In terms of our immediate concerns, that means we have to make every dollar spent for basic research count. I said earlier that our budgets this year were adequate to do the job—but they are just adequate, and we can't afford to let any of it get sidetracked on less than excellent programs. That pressure to select among excellent programs will continue, perhaps even build, in the coming years when it is imperative that we make room for new starts.

OSTP BUDGET

Having taken considerable time to discuss science and technology policy in general, let me move quickly and briefly to the specific subject of the Office of Science and Technology Policy. We are requesting an appropriation of $2.09 million, which is a decrease of $103,000 below the amount currently appropriated in fiscal year 1985. Of that total, nearly 60 percent covers personnel compensation and cost—a total of $1.22 million. This figure includes costs incurred for all people employed by OSTP as well as certain employees detailed to OSTP from other agencies.

We are also requesting $618,000 to cover standard level user charges, communications, utilities, and other rents. The balance of our request—$249,000—covers travel, repair and maintenance of equipment, printing, procurement, supplies, and other administrative expenses.

DETAILEES

Senator, I do want to share a particular concern I have about our ability to carry out the range of tasks that inevitably and necessarily fall to OSTP; for example, my staff has spent great amounts of time on such important matters as the regulatory framework for biotechnology and for radiation. We have continued to chart potential applications for advances in the civil aviation industry. For much of the past year, under the auspices of the White House Science Council, we have been evaluating the readiness of American universities to train the technical talent to meet the challenges of the competitive era we confront. We continue to direct the implementation of the Packard report on the effectiveness of the $18 billion we spend annually for R&D in the Federal laboratories. We work with the Department of Defense on using our technological edge to strengthen our national security. Morever, in addition to our support for the President and the White House offices on questions of science and technology policy, we are regularly called upon to provide advice on an increasing number of issues that science and technology influence. And on virtually a year-round basis we interact almost daily with the major R&D agencies in assessing promising new avenues of research and in helping them plan their future program directions.

I have found that the sheer breadth of issues influenced by science and technology that we must deal with requires an unusual flexibility and mobility of expertise. We meet that requirement by having individuals detailed to OSTP from a wide variety of agencies. OSTP has drawn on staff detailed from as many as 17 different agencies or departments at one time, and right now we have staff on loan from 10 of them. In this way we can concentrate specialists on urgent topics for as long as it takes to complete the work. Unfortunately, while we face increasing needs for flexibility, we confront increasing controls over our ability to seek this breadth of expertise. We were first constrained to an equal number of reimbursable and nonreimbursable detailees. This requirement became even more restrictive last year with the addition of the stipulation that OSTP must provide equal funding for reimbursable and nonreimbursable detailees.

Senator, I do not question the necessity for responsible and accurate accounting for public expenditures. But I do take exception to undue constraints on the detailed functioning of an office whose total appropriation is one-thirty thousandths of the national investment in R&D that it is charged by law to provide leadership for. No other organization in the White House or the Executive Office of the President is subject to such detailed fiscal and management controls. For that reason, I would like to suggest that the restrictive language be deleted from the 1986 appropriation so that OSTP can operate according to the same personnel requirements as other organizations in the Executive Office of the President.

S&T LEADERSHIP

Senator, let me quickly summarize the points I have tried to make here this morning. Our proceedings are dominated by a need for austerity, and we have responded to that need. Because of strong administration and congressional support over recent years, the programs for 1986 will enable American science to stay at the forefront. But our challenge is to make sure that our fragile scientific and technical leadership isn't compromised—either by complacency on the part of others or by misallocation of limited resources by us. If we insist that we will be satisfied with nothing less than world leadership in those things we attempt to do, we can maintain the kind of healthy and responsive climate to continue to recruit the best young minds into pursuit of science and technology, a recruitment that will serve the Nation well in coming years.

That concludes my prepared statement.

[The statement follows:]

STATEMENT OF DR. G.A. KEYWORTH II

Science Advisor to the President and
Director, Office of Science and Technology Policy
Executive Office of the President

To the United States Senate
Committee on Appropriations
Subcommittee on HUD-Independent Agencies

Hearings on Science Policy and
The President's Fiscal Year 1986 Budget for
The Office of Science and Technology Policy

Senator Garn and Members of the Subcommittee:

Once again I'm pleased to appear before this subcommittee to discuss the Administration's priorities in federal programs for science and technology and to present the proposed budget for the Office of Science and Technology Policy for fiscal year 1986. Because this subcommittee also has responsibility for many of the R&D agencies, I'd like to take this opportunity first to talk about science and technology policy in general, then conclude with a discussion of some of the operational aspects of my own office, OSTP.

The start of a new Administration and a new Congress is an appropriate time to take stock and chart a course for coming years. Many of our efforts are going to be concerned with critical choices we have to make in three areas. One is national security--how to create a more stable world and, specifically, how to reduce the presence of nuclear weapons. A second is how we in America can ensure our economic progress in the face of rapidly growing competition in the world's industrial markets. And the third is how we can bring government spending under better control and reduce the deficit that intrudes so rudely on our plans for the future.

Mr. Chairman, I think you'll agree that our enviable lead in science is an important thread that runs through all of those issues--because science and technology are tools to forge our own destiny. They're our leverage on the future.

Fortunately, we go into the 1986 budget deliberations with our science and technology enterprise significantly strenthened over that of not many years ago. The growth of 55 percent in support for basic research over the course of these past two Congresses is restoring momentum to what is one of this country's greatest assets--our scientific enterprise.

In addition, and equally important, this high priority assigned to science by the federal government has elicited comparable high priority in the private sector for using that science. Industry has been increasing its rate of investment in research and development even faster than government has, and in doing so it has also forged productive new partnerships with universities.

But here I have to interpose a cloud into that sunny picture. Our science and technology present may be brighter than it has been in years, but a shining future is anything but guaranteed. Our leadership in science is fragile--extremely fragile. That should concern us deeply, because science plays the same role for technology as a foundation does for a house. Neither structures nor modern industries can exist without those bases of support. And today we depend--far more than most people realize--on our preeminence in science to enable us to exploit technology and maintain our economic and national security.

Mr. Chairman, what I refer to as scientific leadership should not be confused with some kind of academic macho or with taller and more isolated ivory towers. When I refer to scientific leadership I'm describing our national creativity, our ability to be at the forefront of progress, and our ability to meet our responsibility as leaders of the free world. Two events during the past year brought home vividly to me the practical consequences of scientific leadership.

The first was my own experience serving on the President's Commission on Industrial Competitiveness--where I was a lone federal official in a group composed primarily of industrial leaders, few of whom share my technical background and biases for science and technology. Yet it didn't matter if they were bankers, labor leaders, seasoned heads of mammoth corporations, or young entrepreneurs-- all agreed that in the international industrial arena, the United States has only two sustainable advantages over our competitors. Those two advantages are our technology and our talent.

Those industrialists understand better than most people how basic research fuels those two competitive advantages. They also emphasized that, just as they're responsible for maintaining our industrial base, which is fueled by our dynamic free enterprise system, that the federal government is responsible for maintaining our preemient science and technology base--our fountains of new knowledge and technical talent. There was no doubt in the minds of these unquestionably "bottom-line" thinkers that scientific and industrial leadership go hand in hand.

My second observation of the essential role of scientific leadership is evidenced by the Soviet Union's response to the Strategic Defense Initiative, the President's proposal to use our scientific and technological expertise to develop defenses against nuclear weapons. It was the prospect that the United States would use our technological superiority to alter deterrence--and to diminish the Soviet strategic edge--that catalyzed the return of the Soviets to the arms control talks in Geneva.

The Soviets have more than one reason to worry about SDI. In addition to the prospect that strategic defense will make worthless the bulk of their immense offensive nuclear force, our effort to produce a defensive system will almost certainly stimulate a new thrust in technology and leave the stagnating Soviet economy yet further behind.

But here I must share my frustration. The Soviets recognize and justifiably fear U.S. science and technology. U.S. industry, facing a relentless challenge from other countries, especially Japan, places top priority on assuring a strong science and technology base to produce the knowledge and talent we need to compete. And the

American people and today's students know instinctively how directly future economic progress and national security depend on our technological leadership.

As a scientist myself, I can be dismissed in coming before you touting the importance of science to our future. But we can't dismiss what we hear from the Soviets, from our industrial leaders feeling the hot breath of challengers on their necks, and from people across America; they have to be listened to. The President knows that science and technology have been the fuel for our post-war economic growth, yet too many of us in Washington take our preeminence in science and technology for granted. But the truth is that few of our great strengths are more fragile. Unless we recognize the vulnerable nature of this precious leverage, we may find the costs of complacency to be very, very high.

Mr. Chairman, we're challenged this year to balance two dominant priorities. One is to permit investment in our future by reducing federal spending. The other is to assure a strong national science and technology base. The budget being presented to the Congress does both.

Funding obligations for R&D will total $60 billion in fiscal year 1986; of that, some $20 billion will support non-DOD R&D, and $8 billion will support basic research. Funds obligated for non-DOD R&D will decrease slightly from 1985 to 1986, and funds for basic research will increase slightly above the freeze level. Within those proposed budgets I have no doubt whatsoever that we can conduct extremely effective R&D programs.

After four years of near-historic funding increases, there's now plenty of momentum in the system to maintain healthy progress. Moreover, as a matter of practicality, actual outlays for basic research would rise by nearly five percent next year, which should even permit a little real growth. In addition, because we've deliberately postponed the start of construction for major new research facilities for one year, we'll be able to maintain strong funding for on-going research programs. In light of the increased federal support since 1981, there will be no threat to the health of U.S. science. I would even say that, after such rapid growth, sharing in the overall federal austerity may well stimulate sharper delineation of priorities for science.

Mr. Chairman, dealing with budgets necessarily immerses us in what I would call the tactical problems of individual program priorities. Those are the practical steps we have to take to turn policy into reality. However, I also want to urge us to stand back this year and do some extra strategic thinking about science and technology. I say that because I see the central challenge we face as preserving our fragile scientific leadership.

There are two things we have to do. First, we have to embrace our responsibility for basic research. Basic research is as essential to our two highest priorities--maintaining economic growth and national security--as is any other investment we can make today. I won't deny I'm concerned about our ability to sustain the kind of leading-edge basic research program this country absolutely must have. We can't take it for granted. We have to convince others of its importance, and we have to make sure that the current priority for basic research is maintained.

Second, we have to make every dollar count. Science and technology are dynamic processes, kept alive by a constant input of new energy, new people, and new ideas. The worst danger we face is to be lulled into complacency about our leadership and fail to allocate funds wisely. Yes, the United States spends more than $100 billion for R&D in the public and private sectors each year, far more than any of our industrial competitors. And, yes, we have an almost unbroken record of success in amassing prizes for research. But, again, look at American industry and see how a history of success and domination of the marketplace was challenged almost overnight by determined competitors. We who bear responsibility for the readiness of American science better learn from that experience.

I strongly support the necessity of slowing the growth of science and technology funding in the short term as part of the response to the deficit. But at the same time I won't hide my concern about the vitality of U.S. science over the longer term and about its continued attraction for the best young minds. Even the most optimistic forecasters warn us of several years of lean funding until we get the deficit to a level where it doesn't dominate federal budgeting.

As I said, we're in good shape for 1986. Our real challenges will come in fiscal years 1987 and 1988, when we simply will have to find ways to ensure our ability to pursue--and pursue vigorously--new avenues of research. Progress in science won't stagnate--and it won't wait for us. Other countries, facing equally trying times, are renewing their support of basic science. And they're doing it in emulation of our own economic miracle. The last thing we want to do is lose sight of our own successes and what stimulated them. So we'll have to be prepared to make hard choices to fund new starts for high-priority research facilities under whatever fiscal scenario we face in coming years. What will be at stake will be the scientific leadership that we can't affort to compromise.

For example, the nation--or group of nations--that builds the superconducting super collider will become the new world center in high-energy physics. I won't conceal my opinion that it would be a serious blow to U.S. scientific leadership if that facility were built in another country, because a place like that is a magnet for talent and creativity. A big accelerator involves far, far more than the relatively small number of people who can work directly with it, because it stimulates interest in science and excellence far across society and because it inevitably spins off new ideas and technologies.

In the near term our success in providing several new research facilities, such as the Tevatron I and II and the Stanford Linear Collider, puts us in a strong position to maintain our leadership. But we're on notice that over the long haul the leadership in high energy physics is up for grabs. The recent stunning success of a European team working at CERN in Switzerland in detecting the Z° particle was the most important advance in a decade, and it quickly brought the Nobel Prize to the team's leaders. That's a very real reminder that our many years of leadership in that field are, right now, being aggressively challenged.

Likewise, we'll be faced very soon with decisions about proceeding with construction of two forefront research facilities for nuclear physics--the continuous electron beam accelerator in Virginia and the relativistic heavy ion facility, whose initial options are being developed at Brookhaven National Laboratory. Nuclear physics, a field of immense productivity in earlier years, is about to reemerge as one of the most exciting areas of research into the structure of matter, and we have a well-timed opportunity to lead the rest of the world here too.

And we could go on. Will we reassert our leadership in materials science and begin building such next-step facilities as the synchrotron radiation source recently recommended by the Seitz Committee of the National Academy of Sciences? Or do we let the Europeans steal a march on that discipline, a discipline that's becoming critical to advanced technologies in a broad range of modern industries. Someone is going to come up with the next-generation equivalent of microelectronics or recombinant DNA, and I want that someone to be an American. That's not jingoism--it's realism. An it's the spirit of healthy competition that we have to take to heart.

And how will we respond to emerging opportunities in, say, the life sciences? One concern I have is that much of the enthusiasm for funding of the NIH comes from concern for specific diseases, rather than from enthusiastic appreciation of the basic science by which diseases are cured. Consequently, we now see an imbalance in funding approach--a "disease-of-the-month" mentality driving the funding and setting the priorities for one of the most exciting frontiers of science, namely, the biological sciences. It's important that agency missions be supported by strong basic research in those disciplines related to them, whether those missions are health or space or defense. But a mission will be met more effectively by addressing the discipline. For example, it was basic research that found the cause for AIDS. And it will be basic research that will cure cancer. I also worry that funding that's driven mainly by mission is an inefficient approach. It presumes a wisdom that man does not possess, a wisdom that runs counter to our experience that we're very smart when it comes to doing research and very dumb when it comes to predicting where the profound applications will be. Our current system of funding most of the biological sciences because of a presumed relationship to a disease is little more than bureaucratic convenience; it's not the way to sustain leadership in an increasingly competitive age.

The biological sciences stand on a brink of understanding that I can only liken to the brink that Einstein saw for physics in 1905. So it's fair to ask if we are developing the science base we need to reap the benefits that we foresee. Or will we, by remaining captive to past successes and hamstrung by a system of research support inadequately suited to the opportunities ahead, deny our people the advances in medicine and in new industries that others will capture by moving boldly ahead?

One thing to keep in mind is that one can pursue frontier life sciences research on a far smaller scale than is required in most of the physical sciences. It wouldn't surprise me to find newly industrializing nations, looking for opportunities in science and technology, to develop strong capabilities to challenge us in biotechnology. Yet we seem to be giving far too little attention to protecting and capitalizing on our long-term investment in life sciences by broadening the disciplinary base.

Another area of fragility shows up when we fail to maintain a consistent policy to respond to emerging frontiers. Young people have the best noses for tomorrow's hot areas of research, but their career choices can be constrained by prospects for support for research. Uncertainty about support--the kind of uncertainty that results from start-and-stop funding--will effectively chase them away from research careers altogether. Students are unquestionably our greatest resource, and our country is the loser if we fail to attract the best young minds into science and technology.

Last year, for the first time in many years in the United States, the number of applicants to engineering schools grew while the number of applicants to law schools declined. I've joked with some of my lawyer friends that we could call those relative enrollment trends a "Competitive Index" and use it as a positive indicator of how our society is recognizing and responding to competition from other industrial nations. We have the momentum with us now. It would be a shame if that index again turned negative because we failed in our responsibility to maintain a climate to attract our top minds to science and technology.

And let me introduce a practical point here. As we focus upon fueling the engine of technology, there are two logical buttons to push--quality or quantity. Losers push the quantity button, and the engine sputters. Winners push the quality button, and the engine revs up. If we keep our eye on supporting quality, sufficient talent will follow to maintain our technological and scientific lead.

I raise this issue of quality as opposed to quantity because constraints on resources in coming years will continually challenge us to make wise decisions to preserve our leadership. I'm especially concerned about our ability to make long-term plans for the future and carry them out in a timely manner. Science is an often tediously methodical process requiring long preparation. Smaller research facilities may take four or five years to plan for and bring on-line. Major facilities, like a space telescope or a next-generation elementary particle accelerator, can take nearly a generation from inception to completion. It's our mutual responsibility to ensure an optimistic and visionary climate, the American climate, in which scientists and engineers can conduct this sensitive process of planning and bringing on line the tools needed for tomorrow's R&D.

Recently David Packard, a man I consider to be one of our great Americans, observed to me that there are some very close parallels between success in industry and professional sports. He said that three factors determine success. One is the technical skills of individuals, which means that you can't even get started without the basic training and experience. But basic skills are essentially evenly distributed among teams, as they are among competing companies. So the other factors make the difference in the outcome of competition. One is the individuals' zeal to win, and the other is how well they work together as a team. Well, Coach Packard has a pretty good won-lost record over the years, and I'd sure want him in my locker room at halftime. So I'm inclined to take his observation seriously. Happily, in the past few years we've seen a strong rejuvenation of that zeal to win in America, a reaction to the international pressures we've felt on all sides. But we haven't come nearly far enough in developing the kind of team spirit that we also need.

My object in relating this story is to reinforce two points. First, we can't play the industrial game unless we have the technical skills and zeal to surpass our competitors, and that brings us right back to the need for a strong basic research environmnet--the spawning ground for ideas and talent. And second, we need better teamwork. We need to build on the collaboration that's emerged between the Administration and the Congress with regard to priority for science and expand it to include academia and industry too--with all accepting responsibility for making sure we nurture those technical skills and carry them into practice. In terms of our immediate concerns, that means we have to make every dollar spent for basic research count. I said earlier that our budgets this year were adequate to do the job--but they're just adequate, and we can't afford to let any of it get sidetracked on less than excellent programs. And that pressure to select among excellent programs will continue, perhaps even build, in coming years when it's imperative that we make room for new starts.

Sidetracking is an occupational hazard in Washington. We've all felt pressures to support projects in which something other than pure excellence was the driving criterion. Those pressures emerge naturally from our political system, a system that tries to accommodate local interests and national objectives. And we'll find, frequently, that the scientists themselves lack national perspectives, and their advice may be unclear. But let's at least say to each other that we'll do our best to resist those distractions and that we'll focus our attention on those steps necessary to advance our scientific leadership.

Having taken considerable time to discuss science and technology policy in general, let me move quickly to the specific subject of the Office of Science and Technology Policy. We're requesting an appropriation for OSTP of $2,091,000, which is a decrease of $103,000 below the amount currently appropriated in fiscal year 1985. Of that total, nearly sixty percent covers personnel compensation and costs--a total of $1,224,000. This figure includes costs incurred for all people employed by OSTP as well as certain employees detailed to OSTP from other agencies. The full-time equivalent positions for the office will remain at 23 for fiscal year 1986.

We're also requesting $618,000 to cover standard level user charges, communications, utilities, and other rents. The balance of our request--$249,000--covers travel, repairs and maintenance of equipment, printing, procurement, supplies, and other administrative expenses.

Mr. Chairman, I do want to share a particular concern I have about our ability to carry out the range of tasks that inevitably and necessarily fall to OSTP. During the past year, for example, my staff has spent great amounts of time on such important matters as the regulatory framework for biotechnology and for radiation. We've continued to chart potential applications for advance in the civil aviation industry. For much of the past year, under the auspices of the White House Science Council, we've been evaluating the readiness of American universities to train the technical talent to meet the challenges of the competitive era we confront. We continue to direct the implementation of the Packard Report on the effectiveness of the $18 billion we spend annually for R&D in the federal laboratories. We work with the Department of Defense on using our technological edge to strengthen our national security. Moreover, in addition to our support for the President and the White House offices on questions of science and technology policy, we're regularly called upon to provide advice on an increasing number of issues that science and technology influence. And on virtually a year-round basis we interact almost daily with the major R&D agencies in assessing promising new avenues of research and in helping them plan their future program directions.

I have found that the sheer breadth of issues influenced by science and technology that we must deal with requires an unusual flexibility and mobility of expertise. We meet that requirement by having individuals detailed to OSTP from a wide variety of agencies. OSTP has drawn on staff detailed from as many as 17 different agencies or departments at one time, and right now we have staff on loan from 10 of them. In this way we can concentrate specialists on urgent topics for as long as it takes to complete the work. Unfortunately, while we face increasing need for flexibility, we confront increasing controls over our ability to seek this breadth of expertise. We were first constrained to an equal number of reimbursable and non-reimbursable detailees. This requirement became even more restrictive last year with the addition of the stipulation that OSTP must provide equal funding for reimbursable and non-reimbursable detailees.

Mr. Chairman, I don't question the necessity for responsible and accurate accounting for public expenditures. But I do take exception to undue constraints on the detailed functioning of an office whose total appropriation is one thirty-thousandth of the national investment in R&D that it is charged by law to provide leadership for. No other organization in the White House or the Executive Office of the President is subject to such detailed fiscal and management controls. For that reason, I would like to suggest that the restrictive language be deleted from the 1986 appropriation so that OSTP can operate according to the same personnel requirements as the other organizations in the Executive Office of the President.

Mr. Chairman, let me quickly summarize the points I've tried to make here this morning. Our proceedings are dominated by a need for austerity, and we've responded to that need. Because of strong Administration and Congressional support over recent years, the programs for 1986 will enable American science to stay at the forefront. But our challenge is to make sure that our fragile scientific and technical leadership isn't compromised--either by complacency on the part of others or by misallocation of limited resources by us. If we insist that we'll be satisfied with nothing less than world leadership in those things we attempt to do, we can maintain the kind of healthy and responsive climate to continue to recruit the best young minds into pursuit of science and technology, a recruitment that will serve the nation well in coming years.

This concludes my prepared statement. I would be pleased to respond to questions from Members of the Committee.

USDA COMPETITIVE GRANTS

Senator ABDNOR. Thank you, Dr. Keyworth. We will take note of your strong feelings on the challenge on the pay raise. I am sure the committee will at least pay attention to the fact that it is a problem. I fully appreciate the need for research coordination between Federal agencies with similar or overlapping responsibilities. It is less clear, however, what role OSTP plays when fairly discrete missions are exclusively the responsibility of one agency.

In your listing of fiscal year 1984 accomplishments, for example, basic agricultural research is an issue which your Office has described as working closely with USDA on their competitive grants request. This is an area, however, that USDA has been pushing for several years as a policy adopted by that Department.

Would you please describe the nature of the OSTP's role in working with USDA on this issue? I consider it very important.

Dr. KEYWORTH. Thank you very much, Senator, because I think that is about the best example I could give. In fact, in the first speech I ever gave in Washington, 4 years ago, I emphasized the important opportunities before us in agriculture because of the monumental advances in biotechnology. And since we were looking at the full spectrum of American science we attempted to sit down and work with the Department of Agriculture, especially Orville Bentley and the Secretary, himself, to try to see how we could best maintain U.S. leadership in agriculture. I think the relationship has been an outstanding one, and I think that the competitive grant program—particularly the new thrust in biotechnology for agriculture—has been extremely well received within the agriculture community. There is a new vitality and hope and expectation for the future.

Senator ABDNOR. Good. How long has that been going on? How long has the partnership been going on?

Dr. KEYWORTH. I think the real effects of that partnership have been primarily over the last 2 years.

NSF CUTS

Senator ABDNOR. Both sides are most agreeable?

Dr. KEYWORTH. I think it is an outstanding cooperation.

Senator ABDNOR. That is good. Your statement today closely parallels the concerns of Erich Bloch, the Director of NSF. While you argue for greater staff review and analysis on research issues, his priorities are seemingly reversed. For example, the NSF fiscal year 1986 budget cuts policy research and analysis by two-thirds. Do you concur with this proposed reduction in the NSF budget?

Dr. KEYWORTH. Yes. In fact, I worked on that decision thoroughly with Erich Bloch. I think there is no question that we need to focus more and more carefully upon how we coordinate and conduct science policy. I think that Erich Bloch feels, and I thoroughly support him, that there should be a new look within the National Science Foundation at exactly how we meet that challenge and that some changes need to be made, including closer involvement of the disciplinary arms of NSF. And I think that we will be presenting to you in the future a new plan for how we propose to do that. This is a first and important step.

SPACE STATION DEFINITION

Senator ABDNOR. Fine. You seem to be in agreement.

Recently, NASA announced a number of contracts for the definition and design of the space station. You have expressed concerns in the past about how well NASA had considered the definition of this program as well as the viability of some activities stated for the space station, such as materials processing.

Are you satisfied that these concerns have or are being adequately addressed?

Dr. KEYWORTH. I am delighted this year at the breadth and extent to which that very question is being explored. I am not yet satisfied. I will wait until I see exactly what the definition of the space station is and the full scope of parties helping to chart that. If I can be quite candid, Senator, 4 years ago, when I simply asked the question, "I understand what it is, but what is it not?" I found it very difficult to get a comprehensive answer. I think many Members of the Congress shared the same frustration, and I think now there is a wide feeling that there has been an aggressive and active response on the part of NASA to that type of question. So I am quite delighted.

EXPANSION OF SCIENCE AND ENGINEERING EDUCATION

Senator ABDNOR. I am sure when the chairman returns from his experience on the flight, he will have all kinds of new ideas for you to think about, too. [Laughter.]

We continue to be concerned over the number of U.S. citizens pursuing science and engineering careers. You mentioned our responsibility to maintain a climate to attract our top minds for science and technology.

Congress, last year, in an attempt to address these concerns, provided a total of $113 million for NSF to expand science and engineering education activities. The administration, however, has requested that we flatten out this activity to $82 million for both fiscal year 1985 and fiscal year 1986. Don't you see this as a contradiction between our statements and the budget?

Dr. KEYWORTH. Not at all, and let me explain. I think that Erich Bloch, I, people in my office, the National Science Foundation, and elsewhere have spent time on this single issue of improved science, math, and engineering education. The difficulty here is that money does not equal a solution. We have reinvigorated the organization of the National Science Foundation. We have gotten top and active people. Erich Bloch himself, incidentally, became a friend of mine through sharing time on a number of private sector organizations to improve science, math, and engineering education. So, it is a top priority. The solutions are not simple. We are coming up with some very, very interesting programs and options.

The question occupying our time is to be certain that we add high-leverage programs and not throw money at the problem and then complacently go away saying, "We solved the problem." This is one of the most important problems I know in the conduct and improvement of American science. It involves much more than money. The proposal from the NSF is one worked out with us and is responsible in the context of austerity—in using Federal funds for the highest leverage possible.

SUBMITTED QUESTIONS

Senator ABDNOR. Thank you, Dr. Keyworth, for your excellent statement and your fine responses. We have many other questions, but we do have to move along, and we will provide those to you in writing, if you don't mind. I am sure Mr. Jennings will be happy to work on all those. We appreciate having you come before us, and thank you very much.

Dr. KEYWORTH. Thank you very much.

[The following questions were not asked at the hearing but were submitted for response for the record:]

QUESTIONS SUBMITTED BY SENATOR GARN

SHUTTLE PRICING POLICY

Question: Within the current debate over the Phase III pricing period for the Space Shuttle (FY 88-91), a major concern has been raised over the increasing competition from foreign space launch systems -- notably the Ariane. If the shuttle price is raised, the economic viability of these foreign systems will be enhanced, possibly stimulating their future development in not only launch systems, but also the gamut of space technology.

Do you perceive this factor to be a significant concern in the pricing policy debate?

To what degree do you subscribe to the view that commercial firms will refrain from pursuing research and development on space technologies if they perceive that when fully operational, shuttle transportation costs will be significantly above current prices -- that is, how transportation price sensitive do you view these potential space technologies?

Answer: Yes, we do consider the competition from Ariane to be a significant concern in the Shuttle pricing issue. Our response is two-fold.

- The Administration fully intends to comply with the guidance set forth in the National Space Policy to institute full cost pricing for commercial and foreign users.
- The Administration will, through the Office of the U.S. Trade Representative, ensure that the price offered by Ariane indeed reflects the fair and full value.

Commercial firms should rest assured that the Federal government will continue to encourage and support their research and development activities in space. Many of these ventures will require years of development before they can be considered truly commercial activities. Many we suspect will utilize knowledge gained from space-based research to apply directly to their production processes on the ground.

When those firms that intend to pursue manufacturing in space finally reach that state of maturity, we would expect them to pay full costs for their transportation. This is the expectation we hold for the original commercial space business satellite communication.

LEGISLATIVE AND REPROGRAMMING REQUIREMENTS

Question: In past years, this Subcommittee noted that OSTP had violated several funding limitations provisions contained in the HUD Appropriations Bill.

In last year's hearings, we commended you on being more successful in managing your funds within the limitations contained in the law.

This year, however, we are confronted with a significant problem over the requirement that at least half of salary costs of detailees be reimbursed. I understand that rather than immediately implementing this provision, you sought - unsuccessfully - a supplemental from

OMB to maintain your current detailee levels.

What steps have you taken since your supplemental request was denied to comply with the reimbursement requirement?

What is the extent of your current shortfall in funding if your detailee levels are maintained for the balance of the year?

Answer: We have met with Senate and House Committee Members and their staffs to discuss the very serious impact a reduction of detailees would have on our ability to successfully function as an office while addressing the myriad of responsibilities we have. The loss of 4-6 professional staff would simply be devastating to such a small office.

We project a deficit of approximately $240,000 if we maintain current detailee levels.

DETAILEES

Question: You make a persuasive case for the need to pick up technical specialists on a short-term basis to address narrow technical issues which have been assigned to the Agency. I understand, however, that not all the detailees are scientists or technical experts.

Is this correct?

Please provide, for the record, a listing of the detailees serving at OSTP during FY 85 with a description of their GS grade level, their responsibilities, duration of service at OSTP, whether they are on a reimbursable basis and an explanation why each is detailed rather than a permanent employee.

You are requesting that the restriction on detailees at OSTP be removed. The President's budget for FY 86, however, leaves in the restriction.

Has your request been approved by OMB?

How much has been budgeted for detailee reimbursement in FY 85?

What level of reimbursement is included in your FY 86 request?

Answer: There are detailees serving with OSTP that are neither scientists or technical experts. They are those bright, hard working technically oriented support personnel that we must have to assist the scientists and technical experts.

The detailees are in nearly every case on detail because we do not have either the FTE slots or job security most of them desire.

Central Intelligence Agency

Total: 2 individuals. GS 8 and 9 serving in the support area. The GS 8, 14 months, and the GS 9 since August 1981. The GS 8 and 9 are reimbursable detailees.

Department of the Air Force

Currently the Office has two Air Force Lieutenant Colonels on a non-reimbursable basis. One individual is involved in the President's Strategic Defense Initiative, and the other is working in support of the Agent Orange Working Group of the Cabinet Council on Human Resources and the FCCSET Committee for Interagency Radiation Research and Policy Coordination (CIRRPC). One individual has been on the staff for 15 months and the other for 20 months.

Department of the Army

One non-reimbursable Lieutenant Colonel. This individual is currently working in the areas of telecommunication policy, emergency preparedness planning, and "Nuclear Winter". He has been with the staff for four months.

Department of Energy

Four individuals are currently assigned on a non-reimbursable basis. We have one DOE contractor working as the Assistant Director for General Science. The remaining individuals are at the SES 4, GS 15 and 14 levels. They serve as:

Assistant Director for Institutional Relations

Assistant Director for Energy, Natural Resources and International Affairs

A Policy Analyst in the Office of the Assistant Director for Life Sciences

The GS 15 has been on board for 27 months, the SES 4 for 41 months and the GS 14 for 10 months.

Department of the Navy

One Captain on a non-reimbursable basis who serves as the Military Assistant to the Director. In this capacity he is responsible for assisting the Director with his schedule and managing his immediate office. He also provides support in the Defense area. He has been with the staff for 20 months.

National Bureau of Standards

One individual is currently serving the staff in the technical support area on a reimbursable assignment at the GS 7 level. This individual has been on the staff for 20 months.

National Oceanic and Atmospheric Administration

Currently we have one individual on a reimbursable assignment at the GS 15 level. She is providing technical expertise to the Assistant Director for Energy, Natural Resources, and International Affairs and has been on the staff for 19 months.

National Science Foundation

Currently nine individuals are assigned, of which seven are reimbursable. The grade levels are as follows: GS 15(2), GS 14(1), GS 13(1), GS 11(1), GS 9(3), GS 6(1).

Six individuals serve the Director in technical areas and three individuals are used for technical support. These individuals have been assigned to the offices as follows:

GS 15 - One for 41 months and the other 37 months.

GS 14 - Four months

GS 13 - Three months

GS 11 - Eighteen months

GS 9 - One 8 months
One 9 months
One 15 months

GS 6 - 31 months

United States Marine Corps

One Colonel on a non-reimbursable assignment. He currently is serving as the Assistant Director for Defense Technology and Systems. He has been with the staff for twenty-three months.

The FY 85 restriction placed in the OSTP budget language to the Congress mandates that OSTP reimburse other agencies for at least fifty-percent of all personnel compensation of detailees. For FY 85 we have estimated that we will require $407,196 for detailees. Our approved budget authority currently provides for $371,000 without the pay supplemental. This represents a shortfall of $36,196.

Our FY 86 budget request reflects the same level of need.

BUDGET

Question: Aside from the issue of how detailees are accounted for, your budget request for FY 86 shows a net reduction of $123,000 from the level estimated for the current year.

What impact will this have on your activities?

Answer: We had planned to reduce spending in each object class to compensate for this reduction. With the detailee problem this will not be possible as we will have to dedicate any funds we can save below the PCB line to object class (11.8) for the detailees.

US-USSR SCIENTIFIC COOPERATION

Question: Scientific cooperation between the United States and the Soviet Union has been subjected to a number of episodes of constraint in the past decade. Currently, there appears interest to resuming greater scientific cooperation, for example - in space science.

What role is OSTP playing in these initiatives?

Answer: During the last five years the United States' extensive scientific cooperation with the USSR has dramatically decreased as a direct result of unacceptable Soviet actions that this Administration judges to be outside the recognized norms and standards of international behavior. Yet, in spite of this significant reduction in the scope of US-USSR S&T cooperation, the Administration has maintained the structure of many of the S&T agreements with the USSR so when political considerations warrant, the S&T activities under these existing agreements can be revitalized and discussions can begin to restore and perhaps expand scientific cooperation with the USSR in areas of direct benefit to both countries.

OSTP is actively involved in this dual process. During the last year, the Administration approved the extension or renewal of a number of existing agreements--in health areas, the environment, oceanography, housing and agriculture. Moreover, in preparation for the potential resumption of S&T cooperation with the USSR, OSTP is engaged in assessing those areas in science and technology that recognize complementary strengths and will ensure that both parties derive equal benefits from cooperation. One area in which we are assessing the potential for US-USSR collaboration is in space.

There are a number of space activities in which the U.S. could pursue S&T cooperation with the Soviets on the basis of equity and shared benefits. Manned space operations and the increasing capabilities of unmanned research spacecraft afford many extensive and long-term opportunities for US-USSR interactions that offer potential benefits to all mankind.

Examples of areas for cooperation OSTP is reviewing include:

- Cooperative astronaut rescue capabilities;
- Space research to understand and forecast the everchanging and hazardous space environment (or space weather) in which men and women operate;
- Space research to understand energy processes from the Sun to the Earth;
- Space-based remote sensing of the earth to measure global changes that impact the atmosphere, oceans, and land processes.

FY 85 PAY SUPPLEMENTAL

Question: You are requesting an FY 85 pay supplemental of $20,000. How much of the pay raise will you have to absorb?

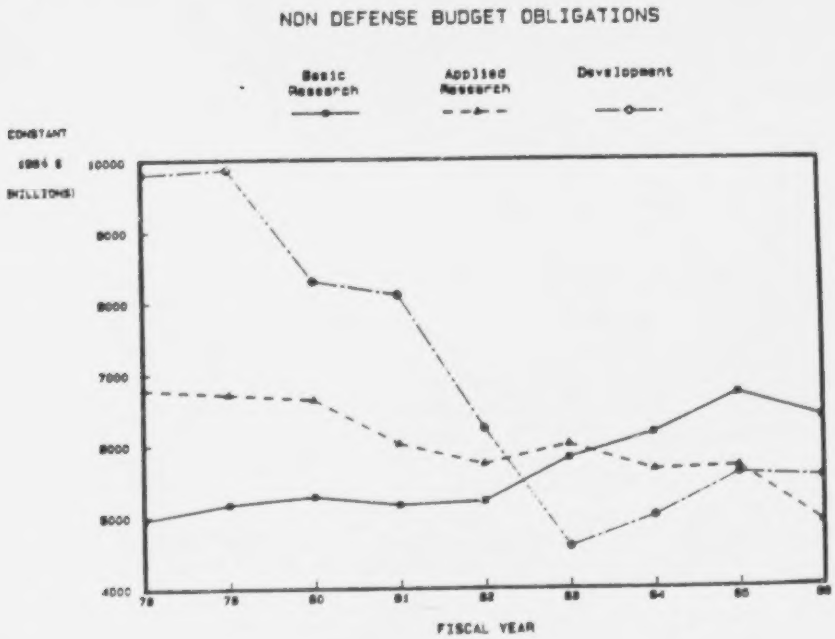
Answer: The $20,000 pay supplemental currently before the Committee represents 50 percent of the amount required for the January 1985 pay increase.

CHANGES IN GOVERNMENT WIDE BASIC RESEARCH FUNDING

Question: Last year, we asked you to provide a chart, for the record, that displayed the changes in Basic R&D funding since 1960.

Could you please update that chart for the record?

Answer: The following update is provided for the record:



WHITE HOUSE SCIENCE COUNCIL

Question: Please describe the activities and funding of the White House Science Council for FY 85 and FY 86.

Answer: The White House Science Council continues to advise the Director on science and technology issues of specific concern to the President. The Council has concerned itself with a number of issues assigned by the Director while also keeping him informed of changing perspectives in the science and technology communities.

The following information is provided concerning the activities of the Council:

March 1982	Advanced Military Technologies Civil Defense National Laboratories Air Traffic Control Appointments to NSB, NSF
May 1982	Federal Lab Panel Report FAA Panel Report Biology and Regulatory Review SNM Panel Report Military Tech Panel Report CIA Techn Transfer Briefing Budget and Basic Science NAS Astronomy Report International

	Defense Energy
July 1982	Life Sciences and Institutional Relations International Affairs FAA Panel Report Federal Lab Panel Report
September 1982	FAA Panel Report Federal Lab Panel Report Falkland Briefing Aero Panel Results Military Tech Panel Report SNM Panel Follow-up and International FY 84 Science Budget
November 1982	Space Program Review Budget and FAA Report Progress and Prognosis Science Program Review and General Discussion Space Program Review and Aero Panel Results India Blue Ribbon Panel Versailles Summit and Energy and Natural Resources Update Briefing on Winrock Report DOD Lab Study Briefing
January 1983	Budget Review MX Briefing Military Tech Panel Briefing US-India Update Nuclear Waste Disposal Science Education
March 1983	Space Program Nuclear Licensing Reform and Legislative Proposals for Natural Gas Deregulation CRBR Fundraising and the Reprocessing Initiative Versailles Summit Report and Williamsburg Summit Plans Federal Lab Study Results of Senior Scientific Panel on Indo-US Cooperation Status Report on Science Education Review of OMB Circular A-21
May 1983	Role of WHSC in Support of President's Defense Initiative (Star Wars) Space Program New Conventional Defense Technology Initiatives Williamsburg Summit Update Status of FAA Panel Report Presentation of Federal Laboratory Review Panel's Final Report US-China S&T Cooperation; Trip Report Acid Rain Peer Review Panel; Status Report
July 1983	OMB Circular A-21 and Indirect Costs of Research

	AIDS Federal Laboratory Study Update R&D Budget Update Executive Scientific Review Panel Progress Report New Conventional Defense Technology Initiatives Supercomputers Science Education Agricultural Research Anti-Trust Law and Joint R&D
September 1983	FY 85 Research Budget OMB Circular A-21 and Indirect Costs of Research Executive Scientific Review Panel Progress Report Status Report on the National Space Program Federal Laboratory Study Update Status Report on Supercomputer Working Group Proposal for Earthquake Engineering Deep Continental Drilling Initiative Keyworth Visit to Israel and Indonesia
November 1983	Role of WHSC in Support of President's Defense Initiative (Star Wars) Japan Science and Technology Budget Update President's Commission on Industrial Competitiveness - Engineering Education Federal Laboratory Review; Progress Report Science and Math Education Earthquake Engineering Research - NAS Study Annual S&T Report
January 1984	Health of American Universities Strategic Threat Review Progress Reports by Chairmen of FCCSET Lab Committee Working Groups - Toni Joseph (DOE), Tim Coffey (NRL), Bob Oswald (ERADCOM), Frank McDonald (NASA) FY 85 Budget Preview Space Station and Manned Lunar Base Discussion President's Commission on Industrial Competitiveness; Status Report Engineering Research and Education Initiative
March 1984	Soviet Sub Threat Evaluation of Arms Control Proposals DIA Briefing Health of Research Universities Implementation of Laboratory Panel Recommendations Supercomputer Access: NSF Program High School Math and Science Initiatives Air Force Agent Orange Study National Lab & Steel Industry Partnership - Update Engineering Research Centers

May 1984	Defense and Arms Control Supercomputers Soviet Technology Transfer Process and Threat Health of University Study - General Comments - Organization/Plan - Indirect Costs The Lab Study Follow-up Update on Steel Initiative Science Budget Status Status of Administration Regulatory Policy - Carcinogen Document - Formaldehyde - Radiation Working Group - Biotechnology - Acid Rain
July 1984	Defense Issues and Follow-up Discussion Regarding SDI and Arms Control PCIC Status Report White House Scholars Program Nuclear Energy DOD and Technical Base Soviet ASAT and Directed Energy Programs Big Science Versus Little Science
September 1984	DS&T Discussion Nuclear Energy Budget Update Lab Study Follow-up and Draft Personnel Legislation Engineering Research Centers and University Institutes SDI and Strategic Stability University Study Risk Assessment and Biotechnology Working Group
November 1984	Agenda '85 Discussion Lab Study Follow-on Tech Transfer/Scientific Communication Soviet Strategic Command and Control Radiation Policy Update Animal Welfare Policy Update Agent Orange Summary
January 1985	Science Budget Discussion re Second Term S&T Reorganization Plan SDI Leadership and National Dependence on Technology Lab Study Follow-on Report Nuclear Winter Briefing Status Report on the National Airspace System Plan Health of University Study

Support of Economic Modernization in China
Update of Radiation Policy
Update of Animal Welfare Policy

During FY 84 $44,337.07 was expended for support of the White House Science Council. We estimate that during FY 85 and FY 86 $50,000 per year will be expended.

QUESTIONS SUBMITTED BY SENATOR LEAHY

ACID RAIN

Question: Three years ago, an expert panel of the National Research Council reached the following conclusion about acid deposition:

> "Continued emissions of sulfur and nitrogen oxides at current or accelerated rates, in the face of clear evidence of serious hazard to human health and to the biosphere, will be extremely risky."

Do you agree with that assessment?

Answer: The question of acid rain today, is not the seriousness of its potential effects on human health and the biosphere, but the methods of transportation and deposition in our environment.

Last Summer, the Acid Rain Peer Review Panel, chaired by Dr. William Nierenberg, released a report which will enhance research and improve our scientific knowledge of the effects of acid deposition on the environment. This report also aims at improving our currently inadequate understanding of the source-receptor relationship.

With a greater understanding of these inter-related factors, our nation, government and industry can go forward to reduce the sources and clean up the environment.

PRICING OF THE SHUTTLE

Question: On page 23 of your justification, you state that you participated in the Cabinet Council on Commerce and Trade Working Group on Commercial Space Initiatives.

What is your viewpoint on the pricing of the shuttle?

If the shuttle price is raised significantly, do you believe it would discourage the development of new uses of space -- such as materials processing?

Answer: The National Space Strategy established a policy of full cost recovery for shuttle launch services provided to commercial and foreign customers starting October 1, 1988. Full cost pricing will only apply to those customers who are fully commercial, revenue generating firms or foreign governments.

The Administration is also working to ensure that all suppliers of launch services also adopt full cost pricing. In this manner, customers for those services can chose, from a freely competitive market, the most cost effective means of transportation.

The pricing formulas were never intended to apply to those firms or governments which intend to conduct research and development activities in space. In fact, this Administration has actively sought to encourage new and innovative experimentation by the private sector through cooperative R&D projects jointly sponsored by NASA. In this way, we plan to foster space commercialization by helping private firms learn to operate in space and exploit new space based processes, yet ensure that fully commercial space operations will reflect the total economic costs of those operations.

STEEL/FEDERAL PARTNERSHIP

Question: On pages 20 and 21 of your justification, you describe a Steel Industry-Federal Research Partnership. The partnership will apparently involve federal facilities and funds. However, you state that, "The steel industry, not government administrators, will ultimately determine the technical directions of the project."

Is this proper? Is it legal?

How can we be sure that these projects will produce technologies which meet federally mandated goals -- such as environmental or occupational health standards -- if the steel industry ultimately chooses the project?

Answer: The technical directions of the industry/federal partnership in steel research are being set by a steering committee composed of representatives from both the steel industry and federal laboratories. Consequently, the steel companies are not the sole determinants of the technical directions of the work. Both steel management and Department of Energy management will approve the scope of the work to be undertaken, and both sectors will be responsible for reviewing the progress of the work.

OSTP finds nothing improper or illegal about this method of defining and managing the research program. To the contrary, such cooperative program definition and management are necessary if the United States is to make effective use of the scientific talent in its federal laboratories.

Concerning the question whether technologies produced by the program will meet other federally mandated goals such as environmental or occupational health standards, technology alone is not federally regulated. Its implementation may be regulated. There is nothing proposed or conceivable in this program which would loosen any regulatory restraints on the steel industry. Both the steel companies and the federal laboratories are sufficiently aware of the regulatory climate in which the steel companies operate to dissuade them from developing any kind of steel process that could not operate within the constraints of foreseeable regulatory policy.

VA BUDGET PRIORITIES

Question: On page 11 of your testimony, you criticize R&D funding at the National Institutes of Health which you believe is too related to one specific disease or another.

In this Subcommittee, we appropriate the funds for Veteran Medical Research. Do you believe that the Veterans Administration's Medical Research Program is dominated by a "disease-of-the-month" program?

Answer: The VA R&D budget does not tend to be disease oriented in the way that NIH is, with the exception of specific veteran-associated conditions mandated by law. The NIH structure around disease-oriented institutes in part fosters the disease-a-month thrust. Mostly, however, the disease-a-month thrust comes from

Congress in response to demands of their constituents and is reflected in the report language of NIH appropriation and reauthorization bills.

R&D

Question: In your testimony, you note that the United States spends more than $100 billion on R&D in the public and private sector each year, far more than any of our industrial competitors.

Yet everyday we read headlines similar to those in last Sunday's New York Times:

"United States Losing Ground in Electronics"

If we are spending at such a high level, why do we appear to be falling behind?

Answer: Commercially available products are the result of a lengthy process of innovation and production in which R&D is only one of several necessary steps or processes. The Japanese high technology success stories of the past decade or so have not been based chiefly on superior R&D. Rather, they have emphasized attention to product quality, serviceability, and reliability. The Japanese have tended to support modern production facilities, good worker/management relationships, and a high perceived performance/cost ratio. Many of our better managed U.S. companies have achieved similar product improvements with similar management initiatives.

The January 1985 Report to the President's Commission on Industrial Competitiveness, "Global Competition, the New Reality," addresses four areas where government and industry together and separately can make changes to keep the U.S. pre-eminent and improve our past economic performance: technology, capital resources, human resources, and trade. The implementation of the recommendations in this report should be a national priority.

REVIEW OF FEDERAL LABORATORIES

Question: In your budget submission, you cite as a major accomplishment a study you coordinated on the use of Federal Laboratories.

What savings in laboratory costs did this panel identify as a result of increased efficiency or consolidation?

Answer: The Federal Laboratory Review Panel did not identify specific savings associated with increased efficiency. The study looked at generic problems which, if corrected, would make the laboratories more productive in solving technical problems and expanding the frontiers of science.

R&D EXPENDITURES IN THE PRIVATE AND PUBLIC SECTOR

Question: You note in your testimony that the combined public/private research and development spending is more than $100 billion per year.

How much of that is public and how much private?

What are the recent trends in the private/public share of basic R&D?

Answer: The following information is provided (Note: Current dollars in billions):

Total R&D By Performer

	Federal	Industry	Other (univ, FFRDC, etc)	Total
1980	7.6	44.5	10.5	62.6
1981	8.4	51.8	11.6	71.8
1982	9.1	58.0	12.2	79.3
1983	10.6	62.3	13.2	86.1
1984	12.3	69.3	14.4	96.0
1985	13.3	77.5	15.8	106.6

Total R&D By Source

	Federal	Industry	Other (univ. FFRDC, etc)	Total
1980	29.5	30.9	2.2	62.6
1981	33.4	35.9	2.5	71.8
1982	36.5	40.1	2.7	79.3
1983	40.3	43.2	3.1	86.6
1984	44.7	48.0	3.2	95.9
1985	49.8	53.2	3.6	106.6

Basic R&D By Source

	Federal	Industry	Other (univ, FFRDC, etc)	Total
1980	5.6	1.3	1.3	8.2
1981	6.2	1.6	1.4	9.2
1982	6.6	1.8	1.5	9.9
1983	7.2	2.0	1.7	10.9
1984 (est)	8.0	2.3	1.8	12.1
1985 (est)	8.8	2.5	2.0	13.3

NUCLEAR POWER PLANTS

Question: On page 29 of your justification, you state that, "Public confidence must be gained in the construction and operation of nuclear power plants. This Office is working closely with DOE and NRC to ensure that happens."

What legislative authority does OSTP have to promote the use of an energy technology?

Why can't the Atlantic Industrial Forum and the American Nuclear Energy Council play this role?

Answer: OSTP is not, nor does it plan to engage in a public relations-type activity concerning nuclear power. This office does, however, believe that sound federal policy requires government involvement in basic research which is presently beyond the normal involvement of the private sector but offering significant benefit to the nation in the long-term.

This nation will likely reach a point, in the early 1990's, where more base-load electrical plants will be needed. Though coal will be the prime source of fuel for any new large generating plants, nuclear power must play a major role in the electrical supply for the coming decades. DOE is pursuing new and improved reactor concepts for the 1990's through the utilization of high technology on the current design of nuclear power plants and the support of the U.S. industry, primarily with the Institute of Nuclear Power Operations (INPO). OSTP has taken a supportive role in these activities at DOE.

Thus, OSTP is not engaging in public relations-type activity. However, DOE and OSTP recognize that through the utilization of high technology in support of safety and efficiency, the public will again strongly support the nuclear option.

DETAILEES - FUNDING

Question: On pages 18 and 19 of your justification, you object to the limitations put on detailees at the Office of Science and Technology Policy.

If the President wants you to undertake a new responsibility, why is he not willing to ask for the funds to do the job?

Answer: This is a period of austerity and each agency has received cutbacks in their budgets. While we received a $431,000 or 17-percent, reduction from our original budget request, we are not asking for an increase in funds. We are requesting the early removal of the burdensome requirement that we reimburse half of our detailees. With our already inadequate budget we are unable to provide funds for half our detailees and maintain anything approaching our current level of operation. Removal of the language will permit us to perform our mission in accordance with the law and as directed by the President.

DEPARTMENT OF THE TREASURY

OFFICE OF REVENUE SHARING

STATEMENT OF MICHAEL F. HILL, DIRECTOR, OFFICE OF REVENUE SHARING

ACCOMPANIED BY:

ROBERT W. RAFUSE, JR., DEPUTY ASSISTANT SECRETARY, STATE AND LOCAL FINANCE

KENT A. PETERSON, DEPUTY DIRECTOR, ADMINISTRATION AND OPERATIONS

CHARLES V. McFADDEN, DEPUTY DIRECTOR, FINANCIAL MANAGEMENT

MARY BETH SHAW, DIRECTOR, FINANCIAL MANAGEMENT

Senator ABDNOR. The Office of Revenue Sharing, I would ask you to come up.

Gentlemen and Ms. Shaw, we welcome you before the committee. You heard me say that you can summarize your statement. I assure you, the entire statement will be made a part of the record.

Mr. Hill, would you please lead off here? Proceed in any way you care to, go ahead on your own, whatever you so desire.

Mr. HILL. Thank you, Mr. Chairman. Since my statement is less than two pages long, if you don't mind, I will read it.

Senator ABDNOR. Say that again. Pardon me?

Mr. HILL. I said since my statement is so short, it is less than two pages, I'll read it.

Senator ABDNOR. Go ahead; you bet.

Mr. HILL. I usually do summarize it, but I would like to read it today.

Senator ABDNOR. I see it is short. Go ahead.

INTRODUCTION OF ASSOCIATES

Mr. HILL. Mr. Chairman and members of the subcommittee, I am pleased to appear before you today to request the appropriation for fiscal year 1986 for the Treasury Department, Office of Revenue Sharing.

Appearing with me are Robert W. Rafuse, Jr., Deputy Assistant Secretary for State and Local Finance on my far right; Kent A. Peterson, Deputy Director, Office of Revenue Sharing on my immediate right; Mary Beth Shaw, Director of Financial Management for the Office of the Secretary on my far left; and Charles V. McFadden, Deputy Director, Financial Management on my immediate left.

Senator ABDNOR. We welcome you all to the committee.

Mr. HILL. In addition, I have with me several key members of the staff of the Office of Revenue Sharing upon whom I may call for information when appropriate.

PROGRAM MISSION AND RESPONSIBILITIES

The Office of Revenue Sharing, a unit within the Office of the Secretary of the Treasury, administers the Revenue Sharing Program. The program was established by the State and Local Fiscal Assistance Act of 1972 and reauthorized in 1976, 1980, and 1983. Payments to local governments under the program are currently authorized through September 1986 at an annual funding level of $4.6 billion, the same as that authorized and appropriated for fiscal years 1981–84.

REVENUE SHARING PROGRAM

The Revenue Sharing Program provides general fiscal assistance distributed by statutory formulas, to approximately 39,000 general purpose local governments. The payments may be expended by units of recipient government for any purposes permissible under the State and local laws, provided that the government adheres to certain nondiscrimination, audit, and public-participation requirements specified in the legislation.

The resources of the Office of Revenue Sharing are primarily devoted to two major tasks: making payments and ensuring compliance with the nondiscrimination, audit, and public-participation standards of the Revenue Sharing Act.

The first task involves obtaining and reviewing the data used in the allocation formulas; computing allocations; making, controlling, and documenting payments; and providing for the collection and control of required forms and information.

The second task involves responding to individuals' complaints as well as judicial and administrative holdings of discrimination, resolution of cases in which public-hearing and notice requirements may not have been met, and ensuring that recipient governments receiving payments of $25,000 or more per year have completed required audits and that all recipients meet minimum standards of accountability for their revenue-sharing expenditures.

PROGRAM OF TECHNICAL ASSISTANCE AND INFORMATION

The Office of Revenue Sharing also conducts a limited program of technical assistance and information to assist recipient governments and the public in understanding their responsibilities and rights under the act. Information and assistance concerning the Revenue Sharing Program are also provided to policymaking officials in other Federal agencies and to Members of the Congress.

As you know, the President has recommended to the Congress that the Revenue Sharing Program's entitlement payments to local governments terminate at the end of fiscal year 1985 and, consequently, no budget authority is being requested for the trust fund for fiscal year 1986. However, the elimination of the trust fund before the end of fiscal year 1986 can only be accomplished through the enactment of legislation by the Congress. It is my understanding that legislation to effect this objective will be sent to the Congress very soon.

SALARIES AND EXPENSES

Mr. Chairman, today we appear before you to request $6 million for fiscal year 1986, for salaries and expenses and an authorized level of 135 permanent positions. We anticipate the need for an FTE of 75 for fiscal year 1986 to oversee the orderly termination of agency activities.

My colleagues and I would be happy to respond to any questions you may have.

Senator ABDNOR. Thank you, Mr. Hill. I guess we can wait to see what really does happen to this program, as a lot of people are strongly supporting it, as you well know. I suppose you have had some calls to your office.

Mr. HILL. We do get some mail.

Senator ABDNOR. As I do also. Seeing what is going on here at this time of budgets, it is difficult to try to predict anything. I am just going to sit back and see how it proceeds since I am not a member of that Budget Committee.

INITIAL OMB REQUEST

What was your initial fiscal year 1986 request to OMB for payments to local government and for the salaries and the expenses of the Office of Revenue Sharing? Whoever cares to answer the question.

Mr. HILL. Our initial request was for $4,574,761,000, sir. That included $8,061,000 for salaries and expenses with 132 average positions, as well as full funding of the trust fund at $4,566,700,000.

EFFECT OF CHANGES ON OPERATION

Senator ABDNOR. What will be the effect of these changes on the operation of the Office of Revenue Sharing, then?

Mr. HILL. The principal effect in fiscal year 1986 of the requested decrease will be the termination of the Revenue Sharing Program. No new payments to local governments would be made after the final payment on October 7, 1985, for the current entitlement period, which is entitlement period 16. The requested 135 permanent, 75 average positions and $6 million in salaries and expenses would be used during fiscal year 1986 to support program and administrative activities associated with the orderly termination of the agency.

Senator ABDNOR. If my memory serves me right, I think I recall reading the Budget Committee proposal that calls for half of that, cutting it in half and going for 2 years with 50 percent of the original amount. I am not saying that is going to take place; I haven't the slightest idea. But if it does, then what happens?

Mr. HILL. If that is the case——

Senator ABDNOR. Do you need all the people you needed before?

Mr. HILL. Yes, sir.

Senator ABDNOR. If they appropriate half as much or not, it is still going to take the same amount of people?

Mr. HILL. Yes, sir; we would need the OMB requested amount.

PROPOSED PAY SUPPLEMENTAL

Senator ABDNOR. Your budget justification identifies a $72,000 fiscal year 1985 proposed pay supplemental. How much of the fiscal year 1986 pay raises will the agency have to absorb, and what will be the implication of absorbing these funds?

Mr. HILL. The cost to the Office of Revenue Sharing for the fiscal year 1985 pay raise during fiscal year 1985 is estimated at $143,000. Anticipated surpluses in planned personnel compensation and benefits funds will allow us to absorb half of these costs—$71,500—with no effect on the office operations.

CONGRESSIONALLY MANDATED STUDIES

Senator ABDNOR. Last year, when questioned by Chairman Garn, you testified that $430,000 was the funding the ORS needed to participate in a mandated 2-year study of the financial relationships between Government and the State, local, and Federal levels.

The ORS later requested a reprogramming of $422,000. Chairman Garn noted that he had thought that additional funding would be required, and since ORS had, on two occasions, been reluctant to ask for more, provided $422,000 with the caveat that no additional funding would be forthcoming.

You recently requested that an additional $96,000 of ORS funds be reprogrammed for the study.

What significant change has taken place recently that could not be anticipated on two prior occasions when this additional funding was not requested?

Mr. HILL. With your permission, Mr. Chairman, I would like to refer that question to Mr. Rafuse, who is in charge of the studies.

Mr. RAFUSE. Senator, if I might, I don't believe that the shift of the $96,000 that you are referring to here represented a reprogramming that was not anticipated in the original planning of the budget. When I testified on this subject last year, I indicated that the cost of the studies would be in the ballpark of $1,500,000 or $1,600,000. I further indicated that the Department had decided that the authorization for a supplemental appropriation of approximately $430,000 would not be called upon because we believed that sufficient resources were available in the existing budgets of the Office of the Secretary of the Treasury and of the other agencies that the revenue sharing reauthorization legislation that mandated these studies directed us to cooperate with—the Advisory Commission on Intergovernmental Relations, the General Accounting Office, and the Commerce Department.

Essentially, we concluded, after reviewing the financial requirements of the studies, that none of the authority for a special appropriation would be called upon and that the resources existed in the budgets of the Office of Revenue Sharing and the Office of the Secretary, and the other agencies to cover the studies. We still believe that to be the case, and so we have not requested and have no plans to request an appropriation pursuant to the special authorization for purposes of financing the studies.

Senator ABDNOR. Would you say that Senator Garn had enough foresight when he provided that extra $422,000? How much was the total?

Mr. RAFUSE. Our estimate—and we recently updated those estimates and provided considerable detail to Mr. Reiss in February on the overall budget for the studies showing that, as I indicated, the resources exist in the budgets of the Office of Revenue Sharing and the Treasury to finance the studies. What this $96,000 represents is a slight change in the mix from individuals on the staff of the Office of Revenue Sharing and other categories in order to complete the study. Such changes in the mix can be anticipated as work goes forward in a study of this magnitude. It does not represent a request for additional funding beyond what we originally anticipated.

Senator ABDNOR. Thank you. I see we have been joined by Senator Leahy.

Senator, would you like to ask questions?

STATEMENT BY SENATOR LEAHY

Senator LEAHY. Thank you, Mr. Chairman. I do have a short statement. If I might, it is nice to have Director Hill and his colleagues here. Your Office, all of you, have been enormously helpful to us in Vermont and the towns and cities of Vermont. I talked yesterday with the head of our Vermont League of Cities and Towns. I continue to hear good things you do for my own hometown.

You know, since 1972, when revenue sharing started, shortly before I was in the Senate, I have seen what has happened. It was started under President Nixon and it is one of the things on which I agreed with him completely on. I think it is the very best in the Federal-State relations. In my own State—we are a small State, and we worry just a tad about the long arm of enormous Federal Government. Just the employees alone of the Federal Government are, in numbers, many, many, many times the population of our own State of Vermont. The President's own budget report is rather interesting this year. It acknowledges that local governments have utilized the Revenue Sharing Program for basic services and set what I thought was a fantastic record for governmental efficiency. They used less than 1 percent of the funds received for administration. That is amazing.

No other Federal program is administered as efficiently, I don't think, Jim, that I can think of, nor more effectively.

The President's response, however, to this model program—here is everything that fits every single criteria for what a Federal program should be—has been to zero fund for fiscal year 1986, a year before its present authorization runs out. I should think that maybe that is the President's new federalism. His old federalism asked the States to do twice as much with half the resources. Now, of course, the new federalism asks them to do twice as much with no resources at all. It is probably a logical progression, but at the next town meeting in Vermont, the logic may escape the town moderator.

The revenue sharing is a lifeline, not only to Vermont's small cities and towns, but in South Dakota and everywhere else. It is the only direct Federal aid agency where nearly two-thirds of all the cities are under 10,000 population. That is about the majority of Vermont, where our median is around 2,500.

If you haven't ever been to a Vermont town meeting, I suggest you should go. You would enjoy it. You would find it is a very interesting place. The people are very friendly. The Bob Newhart Show just did one of their own on town meetings. I found, if anything, it is less humorous than what happens, but it is worthwhile. The most worthwhile thing is people go in and debate issues. Everything stops in our State at a town meeting. I don't mean to give you a lecture on Vermont, but it is a point, because it is participatory democracy at its absolute very best.

One thing you know, if you go to those town meetings, you know Vermonters have to be the most frugal, careful people with their money you have ever seen. And we have to be, because we are only a half a million people. Our State and local tax burden is already one of the highest in the Nation. Unlike large cities, Vermont's towns are almost exclusively dependent on property taxes to support local services.

You take away $12 million that Vermont now receives in revenue-sharing funds and Vermont towns have two clear choices: Either raise the property taxes, which have already gone as high as they possibly can, or cut essential services. Without revenue sharing, the small towns in our State—and I suspect it is the same in most other States—simply couldn't afford to adequately provide services such as police and fire protection, health and sanitary services, and a myriad of programs that help the aged, the poor, the handicapped. We all recognize the serious deficit problems facing the country. We realize there are a lot of essential expenses. I agree that we don't need to buy $600 coffee pots and $700 toilet seats. I don't want our Nation's defense to be in any way shortchanged, and I want those coffee pots to be able to work at 100 degrees below zero at 100,000 feet altitude. Even though everybody around them would have died, at least we will know everybody is gone and the coffee still perked. [Laughter.]

I think part of our national security is our own people, our 225 million people in those cities and towns, that is part of our national security. That is part of one of the reasons why we have our Government, and we want to protect that. Those people are willing to do their share. They want to be treated fairly. They don't want to say, "OK, we will cut all this out. We will do all these things and raise our own taxes and we will somehow provide for just the absolute minimum of fire protection and police protection and all, but the only thing we are accomplishing out of that is to take all the money out of our pocket and put it into an already extraordinarily large pocket."

So, I don't think it is fair; I don't think it is sensible to completely cut off the revenue-sharing lifeline to towns, now, after they have spent the last 4 years cutting the budget and raised the taxes to compensate for the first round of the President's budget cuts. They know the budget has been cut so more money can go to the Department of Defense. Maybe people like that. Maybe that is a valid thing to do, to bankrupt and strap our cities and towns, to put the money into the Department of Defense. I don't say that sarcastically. Maybe that is a policy choice we might make, but these towns and cities have been doing that, and they have been cutting themselves to the bone. My God, don't all of a sudden just turn the spigot off and say: "That's it." Just totally bankrupt your towns and, in some instances, become ghost towns because we have better uses for that money.

I don't believe it.

Senator ABDNOR. Thank you for the statement.

Senator LEAHY. Sorry. It is the longest one I have given in this committee, Mr. Chairman. I won't do it again.

Senator ABDNOR. I mentioned earlier that there are some strong feelings on those subjects.

Senator LEAHY. There are a couple out there. They ought to hear some of the discussions in the cloakrooms on both sides of the aisle, I might add, on that one.

Senator ABDNOR. We have a number of questions that I am submitting for the chairman in writing. Would you care to ask any or submit any?

Senator LEAHY. I will submit some, but I do have a couple, Mr. Chairman, if I might.

Senator ABDNOR. Go right ahead.

THE PRESIDENT'S DECISION

Senator LEAHY. In 1983, the President signed the legislation authorizing the General Revenue Sharing Program to fiscal year 1986. At the signing sermon, he said, "The Federal Government never spent more money wisely than by devoting it to revenue sharing." Now, his budget for next year calls for the program to be abolished 1 year before its authorization ends. Did I miss something in between there? [Laughter.]

I try to read the paper everyday. I listen to the radio on the way home on the news stations. I feel guilty when I turn it on to my favorite country music station that I may have missed something, but what was it? What did I miss? [Laughter.]

Mr. HILL. You didn't miss anything, Senator. I am convinced that the President's decision was not an easy one to make, to terminate a program like revenue sharing. I am sure it was made after much thought. It was according to testimony given by other administration officials, a decision——

Senator LEAHY. I can't hear you. Can you bring the mike up to you?

Mr. HILL. I said, according to the testimony I have heard of other administration officials, it was a decision that was brought directly to him, to the President to make, and I am sure that it was made after much thought.

If my colleague, Dr. Rafuse, would like to amplify upon that, I would be glad to defer to him.

Mr. RAFUSE. Senator, a lot has been said in the past few months, and a lot more will be said, about the desirability of terminating the Revenue Sharing Program. I think that the essential logic of the position the President has taken is that the vast bulk of the funds distributed under that program go to local governments that are entirely capable of raising revenue from other sources and they don't need the Federal support. I think that is the essential logic of the decision, that this program does not represent a high enough priority to retain it on the books in the face of the large Federal deficit. As the President has said, we can't afford programs of this sort any longer when such a large proportion of the funding goes to such local governments as Fairfax County, VA, and many, many others, that have entirely sufficient capacity to raise the limited amounts of funding they receive from this program from their own resources. The Federal support is simply not a high enough priority to justify retaining the program in the face of the severe budgetary problems we have.

Senator LEAHY. For every anomaly like Fairfax County or Beverly Hills, I can give you hundreds and hundreds and hundreds of counties all over this country who don't have that surplus. They are operating right on the bone. They have to keep balanced budgets, are required to keep balanced budgets, either by the charters, constitutions of the State, or whatever; they do not have the printing press capacity of this Government. Now they are suddenly having the rules changed, boom, a year early, having already cut everywhere they can, and quite frankly, are beginning to understand more and more where that money is going, and it is not going to anything that is going to aid them.

You may have a Fairfax County and you may have a Beverly Hills and you may have a couple of places like that. You know and I know, that they are the exception; they are not the rule for this country.

That is not directed at you personally, but you understand what I am saying. As I said earlier, your whole Office has been extremely helpful in working with Vermont, and I appreciate that, and I want that publicly stated here that I mean it very sincerely. I have seen one study where it says State and local governments have a surplus equal to 1.9 percent of expenditures. That is barely enough to cover cash flow, not enough to cover $4.6 billion of lost general revenue sharing funds. Where do we have a responsibility to the people? I must point out that on Monday I was speaking to one of the largest defense contractors in this country. I told them exactly the same thing. I think at about the end of it, they looked around to find out which one of the idiots around the table invited me out there to speak. [Laughter.]

I am saying to them: You have got to understand, we are going to have to start talking about not arms negotiations in Geneva, but arms negotiations here at home if all this is going into the pockets of just a few.

My own State has some major defense contracts. I think on a per capita basis, we probably are one of the highest in the country. But that, this either/or kind of balance that we are getting into just doesn't make any sense. I am afraid what it is going to do is, it is going to damage the internal fabric and thus our national security, the internal fabric of our country, and that is part of our national security. It is in farm programs; it is in all these other programs. That is part of our national security.

So, I tell you, I cannot support and will not support cutting off revenue sharing this year. I will look for cuts and will vote for cuts, some very painful cuts, painful to me in other parts of the budget to do it, but I am not going to vote to cut this out.

Thank you. That is it.

Senator ABDNOR. Senator, I have to impose the 5-minute rule here. I know Senator Proxmire is here for a purpose.

Senator Proxmire?

Senator PROXMIRE. Thank you very much. I disagree with my good friend, Pat Leahy. He is right about a lot of things. He is wrong about this one.

Senator LEAHY. Stop beating around the bush, Bill. [Laughter.]

Senator PROXMIRE. Revenue sharing ought to be the first to be axed and I will tell you why. Revenue sharing ought to be the first to be axed because we don't have any revenue to share, No. 1; and No. 2, the Senator from Vermont pointed out that some of these economies have a 1.9 percent surplus. We don't have any surplus at all. When you have a deficit, you have less than you have when you have nothing, and that is exactly what we have. So I think that the Revenue Sharing Program which is a program which adds little merit, not very much, ever, because the people who spend the money are spending it without any real accountability. Again and again and again I have heard people say: "Don't worry about our spending the money on the golf course or the new fire engine. After all, it is not your money, it is Uncle Sugar's money. It is not the money you have to pay in your property taxes."

I think this program has to be phased out. Let me ask you this: What level of funding would you need if we followed the Senate Budget Committee recommendations of cutting revenue sharing 50 percent in each of the next 2 years and then terminate the program in the third year?

Mr. HILL. What we would need, Senator, would be our final request to OMB, which was for $7,785,000 for salaries and expenses with 130 average positions.

Senator PROXMIRE. $6 million is not the figure in the statement; is that right?

Mr. HILL. If the scenario you just outlined were put into place, the answer is yes, we would need full funding. Because the reduction of the trust fund amount doesn't——

Senator PROXMIRE. So the administrative costs would have to remain the same?

Mr. HILL. Yes, sir.

Senator PROXMIRE. So the overhead cost will increase on a percentage as we slowly end the program?

Mr. HILL. Yes, sir.

Senator PROXMIRE. All right, sir. That is one of the reasons why it seems to me that it makes sense for us to cut it out as the administration recommends. With a great respect, admiration, affection for Pat Leahy, who is one of the very best, I must respectfully disagree.

Senator LEAHY. Oh, shucks. [Laughter.]

Gathered that. I figured that out. I haven't been running for 10 years for nothing. I was able to figure it out almost through the first half of your statement.

Senator PROXMIRE. You have always been a quick study, Pat. [Laughter.]

Senator ABDNOR. The Senator appreciates hearing such kind remarks.

Senator LEAHY. It ain't the first time.

SUBMITTED QUESTIONS

Senator ABDNOR. I think I can now say that we appreciate your attendance here, and we have other questions that we will be submitting in writing.

Mr. HILL. Thank you, Mr. Chairman.

Senator ABDNOR. Thank you.

Senator LEAHY. Thank you.

[The following questions were not asked at the hearing but were submitted for response for the record:]

QUESTIONS SUBMITTED BY SENATOR GARN

PROPOSAL TO TERMINATE GRS

Question: Would you please briefly describe the effect on your three major activities (in terms of dollars and personnel reductions) of implementing the proposal to terminate the General Revenue Sharing Program authorization and phase-out the administrative effort?

Answer: Funding and personnel reductions in the three major Office of Revenue Sharing (ORS) activities that would be associated with implementing the proposal to terminate the Revenue Sharing Program are summarized in the following table, which appears on page ORS-2 of the Office's FY 1986 budget submission.

	FY 1985 Adj. 1/		FY 1986 Est.		FY 1986 Program Changes	
	Ave. Pos.	Amt.	Ave. Pos.	Amt.	Ave. Pos.	Amt.
Legal and Support Services	25	$1,346	16	$1,112	-9	$-234
Operations and Technical Assist...	38	2,904	18	2,129	-20	-775
Monitoring and Enforcement	67	3,535	41	2,759	-26	-776
Total	130	$7,785	75	$6,000	-55	$-1785

The FY 1986 program change is based on the proposal to terminate the Revenue Sharing Program authorization on September 30, 1985. The reduction of $1,785,000 and 55 average positions in the Salaries and Expenses account will leave sufficient resources available to complete the closing down of the operation by September 30, 1986.

As indicated in this table, the proposed reductions in funding and personnel represent across-the-board decreases in the three major Office activities, Legal and Support Services, Operations and Technical Assistance, and Monitoring and Enforcement, among which Executive Direction has been spread to permit a more representative presentation of the actual cost of each activity.

The funding and personnel figures presented in this table are the result of an analysis of the costs and staffing requirements associated with the proposed FY 1986 phasing out of the administration of the Program. The analysis included identification of critical staff positions in each of the three major ORS activities and estimates of how long various positions' services would be required during the FY 1986 close-down process. Although this analysis provides a basis for FY 1986 planning, actual average-position and cost figures might vary considerably as a result of unmanageable attrition.

1/ The FY 1985 authorized level of $7,923,000 has been adjusted to take into account the following other category changes: the effect of the Civilian Pay Raise annualization; the Pay Reduction of five percent effective January 1, 1986; and the Administrative Services cost reduction of ten percent and two average positions.

BACKLOG OF CIVIL RIGHTS CASES

Question: Last year you stated that the backlog of unresolved discrimination cases should drop to 660 as compared to the 757 case backlog at the end of FY 83. Your goal for FY 85 was to be 517 cases. What are your revised plans in the civil rights area and are you setting any caseload goal for FY 85?

Answer: The Civil Rights Division is currently conducting a review of the case handling process for the purpose of identifying those procedures which may be unnecessarily cumbersome and can be modified in a way which will result in decreasing the processing time for case resolution. A preliminary review indicates that there are several stages of case processing which can be modified without harm to the quality of work being produced. It is our plan to revise the processing procedures, as appropriate, by May 1, 1985, and to adjust production goals, toward the end of significantly reducing the backlog before the end of FY 1985.

With five months completed in FY 85, we have revised our estimates based on actual date as well as management initiatives directed at reducing the backlog. We project that we will end FY 85 with approximately 650 unresolved cases. It should be noted that the actual beginning backlog for FY 85 was 872 unresolved cases (as opposed to the projectd 660). It should also be noted that by March 1, 1985, the open case backlog had increased to 893. However, 272 of that number were cases which were in various stages of the post-investigative process, reflecting the backlog of uninvestigated cases to be only 621.

FY 1985 APPROPRIATION RESCISSION PROPOSAL

QUESTION: Your budget justification identifies a $90,000 FY 1985 Rescission Proposal for the Deficit Reduction Act of 1984 (Section 2901 Savings).

Would you please identify the major components of this Rescission Proposal and break out the funding for each component.

ANSWER: The major components of the $90,000 Rescission Proposal for the Deficit Reduction Act of 1984 (Section 2901 Savings) are as follows (dollars in thousands):

Object Class	Category	Section 2901 Proposed Rescission
1100	Personnel Compensation .... Public Affairs, Public Relations and Advertising Activities	$ 7
1200	Personnel Benefits .... Public Affairs, Public Relations and Advertising Activities	1

2100	Travel and Transportation of Persons	25
2400	Publishing, Printing, Reproduction and Audiovisual Activities	7
2500	Consultant Services	50
	Total	$90

Deficit Reduction ($90): This reduction includes ten fewer trips to assist recipient governments with their efforts to adhere to administrative and compliance requiremnts of the Act, thirty-nine fewer civil rights compliance case investigations, twenty fewer reviews of State and IPA audits, significant delay in the provision of clerical support to the correspondence control unit, elimination of at least two pay letters providing recipient governments with essential compliance information (e.g., compliance with the substantive and administrative requirements of the handicapped discrimination regulations), and thirty-six fewer investigations by State compliance agencies of alleged non-compliance with provisions of the Act.

FISCAL CONDITION OF STATES AND LOCAL GOVERNMENTS

Question: What is your assessment of the fiscal condition of State and local governments compared with this time last year?

Answer: No one doubts that the fiscal condition of State and local governments has improved substantially during the past two years, as the economy has recovered from the recessions of 1980-82, and that they can now be said to be basically healthy. If the economy remains strong, the outlook for the State-local sector is bright.

There are a number of indicators of improved fiscal health. The other-funds surplus of the State-local sector in the national income accounts increased significantly last year. The other-funds measure was in slight deficit in 1982 ($0.6 billion), in surplus in 1983 ($6.6 billion), and rose to an even more substantial surplus in 1984 ($10.3 billion).

In 1984, the States in the aggregate approved few discretionary increases or decreases in taxes, after large net increases enacted in 1982 and 1983 to cope with the revenue shortfalls produced by the recessions. The Governors have proposed tax changes in 1985 that appear, overall, to amount to recommendations that States enact small net tax decreases.

Compared with spending measured on a current-services basis, the State-local sector approved about $5 billion of spending increases in 1984. Those increases recovered a portion of the reductions in spending made during 1980-83 in response to the fiscal pressures arising from two recessions and the continuing decline in the real level of Federal grants per capita that has been in progress since 1979. The cumulative decline in the real value per capita of Federal grants during the five years, 1979-83, was about 25 percent. Capital and education spending increases led the way in 1984. The 1985 budget recommendations of the Governors call for more spending increases.

You may have heard of the current-services projections model for the State-local sector that is run by the Treasury Department. If the economic assumptions of the Administration made in the FY 1986 Budget are realized, and if the State and local governments make no discretionary changes in their revenue systems or current-services expenditure levels, 1985-89, the sector could be expected to realize a $44 billion other-funds surplus in 1989. This projection assumes that the grant reductions proposed by the Administration in the FY 1986 Budget are fully implemented. Of course, the projected surpluses will not actually be realized. The tendency of the budgetary processes of State and local governments is to attain equilibrium at approximate other-funds balance in the national income accounts. Thus, receipts would be decreased or expenditures raised to take advantage of the projected fiscal discretion.

Last year, the Treasury reported that the fiscal outlook for the State-local sector was bright. There is no reason to change that assessment based on the information now available about the current fiscal condition of the sector and the outlook.

EFFECT OF GRS TERMINATION ON THE STATES

Question: What would be the effect on the States of an elimination of General Revenue Sharing funds?

Answer: There would be negligible longer-term fiscal consequences for State and local governments from a termination of the Revenue Sharing Program. It represents about one-half of 1 percent of the own-source, general revenues of State and local governments and 2.2 percent of the own-source, general revenues of localities. Given the modest role of Revenue Sharing in local budgets, adjustments to this termination would have scant adverse consequences over the longer run.

In the short run, most recipient local governments would have little difficulty adjusting to termination of the Program. Revenue Sharing represents 4 percent or less of the total budgets of the overwhelming majority of the Program's 39,000 recipients. With few exceptions, these governments have the fiscal capacities to easily make up for the loss of these funds.

There are a few, generally small, very poor, and largely rural jurisdictions for which a loss of Revenue Sharing would constitute a real hardship. Since payments to such jurisdictions represent less than 20 percent of the Program's funds, their potential hardship certainly provides no justification for maintaining a $4.6 billion program. The inadequate fiscal capacities of these jurisdictions have been shaped by choices made by State governments, and it is the clear responsibility of State governments rather than the Federal government to ensure that all local governments have fiscal resources to fund their essential service responsibilities.

LOCAL GOVERNMENT TAXES AND EXPENDITURES VERSUS GRS FUNDS

Question: Last year, you testified that in FY 1982 the percentage that Revenue Sharing funds represents of local government tax collections was 7 percent and in terms of local government expenditures, it was 2.5 percent. Would you please update these figures?

Answer: For Fiscal Year 1983, the latest period for which statistics are available, total Revenue Sharing funding ($4.6 billion) was 6.4 percent of local government tax revenue ($71.2 billion) and 2.3 percent of local government expenditures ($196.5 billion). Revenue Sharing funding as a percent of local government tax revenue and expenditures is declining because Revenue Sharing funding has been constant while local government tax collections and expenditures have increased. These figures pertain to general purpose local governments.

NYC LOAN GUARANTEE PROGRAM

Question: Although the Secretary's authority to issue guarantees expired on June 30, 1982, and the administrative expenses of the Loan Guarantee Program shifted to the Office of the Secretary, the Subcommittee still continues to be concerned with the Secretary's responsibility to monitor the program until the City's obligations are fulfilled. Last year you indicated that you would be done with the Program within the next three years. Is this schedule still valid? Do you have any general comments on the status of the New York City Loan Guarantee Program?

Answer: With respect to the first question, yes, the schedule is still valid. As Treasury's testimony indicated last year, the New York City Loan Guarantee Act requires that, beginning in City Fiscal Year 1983, the City prepay Federally guaranteed bonds in an amount equal to 15 percent of the net proceeds raised by the City in the public credit market in a given year. This provision is the reason that the Program will end in City Fiscal Year 1987, six years ahead of the schedule implied by the original maturities of the bonds. We fully expect that the City will adhere to this schedule.

As to the status of the Loan Guarantee Program, we believe that the key objective of the Program--the achievement of full re-entry in the long-term credit market--has been just about realized. The City first reentered the long-term credit market in 1981 with a public issuance of $75 million. At that time, the City was unable to meet its financing needs alone and depended upon the proceeds raised by the Municipal Assistance Corporation (MAC) and, of course, the issuance of Federally guaranteed bonds. Now, four fiscal years later, the City appears to have achieved market access. The Federal government and MAC no longer supplement the City's financing efforts. In the current fiscal year, the City has issued $1.0 billion of its general-obligation bonds. Of this amount, $227 million is to be used to prepay Federally guaranteed bonds.

With respect to the ratings of the City's general-obligation bonds, Standard & Poor's has assigned a BBB rating and Moody's has assigned a Baa rating--both investment grades. Despite the continued success of the City in the public credit market, the sound performance of the City's economy, and the health of the City's budget, these agencies have yet to reassign the more favorable ratings that were in effect before the onset of the Fiscal crisis in 1975. At that time, both agencies assigned an A rating to the City's bonds.

QUESTIONS SUBMITTED BY SENATOR LEAHY

ELIMINATION OF REVENUE SHARING

Question: The General Revenue Sharing Program has supported basic services and capital improvements at the local level for twelve years. If cities have to immediately replace their Revenue Sharing payments with local property taxes, it is estimated that cities nationwide under 10,000 would have to raise their taxes by as much as 50 percent. Vermont officials anticipate at least a 12 percent increase in property taxes to make up for the lost funds. Is it fair or realistic to eliminate the Program abruptly next year as the President has requested?

Answer: The Administration is well aware that termination of the Revenue Sharing Program would force some difficult adjustments for a small number of the Program's 39,000 recipients. However, the President believes that these difficulties are more than offset by the pressing need to reduce the Federal budget deficit.

Question: Now towns in Vermont and elsewhere find themselves hostage to the uncertain fate of the Revenue Sharing Program. If Revenue Sharing has to be cut somewhat to contribute to our common goal of deficit reduction, doesn't it make a lot more sense to give the towns a phase-out timetable over several years so they can make adjustments in their budget and tax planning?

Answer: The overwhelming majority of local governments should be able to adjust to the termination of Revenue Sharing without substantial difficulty. Since 1976, the value of Revenue Sharing payments to local governments has declined steadily due to inflation and the Program's fixed funding level. In other words, the Program has been phasing down for almost a decade. Further, local governments have been aware since January that the President has proposed that payments be terminated at the end of the current fiscal year. Local officials tend to be prudent financial managers, and most have probably initiated plans to cope with the termination of the Program.

TARGETING OF REVENUE SHARING

Question: Would you say that General Revenue Sharing is a targeted program? In other words, do communities whose citizens have low per capita incomes receive higher amounts of Revenue Sharing funds per capita than more affluent areas?

Answer: It is the conclusion of both the Treasury and GAO that Revenue Sharing is a moderately targeted program. However, about two-thirds of Revenue Sharing funds go to jurisdictions with per capita incomes over 85 percent of the average per capita income of their States. Such jurisdictions are capable of financing their service responsibilities from their own sources, and it is likely that a substantial portion of these Revenue Sharing payments simply end up reducing the tax burdens on the residents of those jurisdictions. Given the acute pressure on the Federal budget, it simply does not make much sense to finance tax relief for localities that have no real need for general fiscal assistance from the Federal government.

LOCAL TAXES AND REVENUE SHARING

Question: If a community is forced to reduce its local taxes because of a decline in local property values or a state tax limitation, what will be the impact on its Revenue Sharing payment?

Answer: The statutory formula used in the allocation of Revenue Sharing funds among local governments within States takes three factors into account--population, tax effort, and per capita income. The population and income factors measure the relative need of governments, while the tax-effort factor measures a government's commitment to meeting its needs from its own resources. The allocation formula is designed to provide greater assistance to those governments with lower per capita incomes and higher tax effort than other governments in their States and County areas.

If a community's actual tax collections decline or fail to grow as fast as those of other local governments in its county or State, its Revenue Sharing allocation will usually diminish. Tax collections can decline for many reasons. The local government may have cut its tax rates either on its own initiative or because of a State tax limitation. Reduced assessed property values because of adverse economic conditions could also lower the taxes collected by a government. No matter what the reason for the decline, lower tax collections relative to those of other governments in the State or county area tend to reduce Revenue Sharing allocations. Offsetting factors, such as larger State area or county area allocations because of increased taxes by other governments, could lessen the impact of a local government s lower taxes.

It is important to realize that the effects of declining tax collections on Revenue Sharing allocations are delayed until those data are used in the Revenue Sharing formula. For Entitlement Period 16 (October 1, 1984 to September 30, 1985), the Revenue Sharing allocation is calculated based on the tax data for local government fiscal years ended between July 1, 1982 and June 30, 1983.

Question: Do communities use these funds for essential municipal activities?

Answer: Local governments are required to appropriate Revenue Sharing funds to specific activities, but the objects of these appropriations rarely reveal the real fiscal impacts of the payments. The real fiscal impacts of Revenue Sharing are basically the same as those of an increase in a local government's property tax revenues. It would not be rational for a locality to treat the funds in any other way.

For example, local officials are occasionally quoted as suggesting that they use Revenue Sharing funds to finance low-priority programs to minimize the pain if the payments were to be cut off, and some conclude from this that Revenue Sharing funds are not used wisely.

This is an incorrect interpretation. These local officials are not saying they are using the funds frivolously. They are merely saying that they are treating the funds as an increment to local resources, but they are presumably appropriating the funds to their highest priorities at the margin. To do otherwise would not be prudent budgeting. Thus Revenue Sharing funds support services that are normally financed from the recipient's own revenue sources and/or hold down local tax rates.

Question: Could you describe the relationship of Revenue Sharing funds to local taxes? Are large or small communities more dependent on the funds?

Answer: For fiscal year 1983, the most recent period for which local tax data are available, total Revenue Sharing funding ($4.6 billion) was 6.4 percent of local government tax revenues ($71.2 billion) and 2.3 percent of local government expenditures ($196.5 billion). Revenue Sharing funding as a percentage of local government tax revenues and expenditures is declining because the amount of funds authorized for distribution to local governments has not increased since 1977, while local tax collections and expenditures have increased. These figures pertain to general-purpose local governments.

Revenue Sharing allocations as percentages of the taxes and total expenditures of general-purpose local governments in fiscal years 1975, 1980, 1981, 1982, and 1983 are shown in the following table.

	Fiscal Years				
	1975	1980	1981	1982	1983
Taxes	11.2%	8.3%	7.6%	7.0%	6.4%
Expenditures	5.0	3.0	2.7	2.5	2.3

In general, Revenue Sharing funds constitute somewhat larger proportions of the total revenues of small governments than of large governments.

LOCAL GOVERNMENT FISCAL STATUS

Question: Would you say that the local governments your office deals with have large surpluses that make the loss of Revenue Sharing funds trivial?

Answer: Local governments very rarely run large surpluses in their operating budgets because to do so would be poor financial management. At the same time, they almost never run deficits because they are required by law to balance their operating budgets. (Borrowing to finance capital outlays is, of course, a common and prudent budget practice.) This means that the actual size of a local government's surplus is a poor indicator of the difficulty that government will have in handling the loss of Revenue Sharing funds. For most localities, if the economy remains strong, the loss of Revenue Sharing will be more than made up by the automatic increase in revenues from the locality's own sources in one year. The loss of a year's worth of revenue growth is not a trivial matter for any government, but neither is it an extraordinary price to pay for real progress in eliminating the Federal budget deficit, which is essential if the economy is to remain strong.

Question: Do you feel that the Federal Government Tax System is more progressive than the property tax system that most local governments are forced to use by their state governments?

Answer: The Federal income tax is progressive since the rate of taxation increases as taxable income increases. For example, if the taxable income of unmarried individuals is below $2,300 for 1984, no Federal income tax is imposed. At the $20,000 taxable income level, the marginal rate of tax is 26 percent. Taxable income in excess of $81,000 is taxed at 50 percent.

In general, studies suggest that the property tax is either roughly proportional to income or slightly regressive (in that the increases in amounts of tax paid do not rise as rapidly, in percentage terms, as income).

ADMINISTRATIVE COSTS OF REVENUE SHARING

Question: What are the administrative costs of the program expressed as a percentage and how have they changed over the past few years?

Answer: The costs of administering the Revenue Sharing Program at present and over the past few years, expressed as percentages of the Trust Fund Appropriation, are as follows:

FY 1982	FY 1983	FY 1984	FY 1985
0.13%	0.15%	0.16%	0.17%

The rise in this ratio has occurred because the Trust Fund appropriation has been constant since FY 1981, while salary increases and inflation have raised the costs of administering the Program.

CONSUMER PRODUCT SAFETY COMMISSION

STATEMENT OF TERRENCE SCANLON, CHAIRMAN

ACCOMPANIED BY:

SAUNDRA BROWN ARMSTRONG, VICE CHAIRMAN
CAROL G. DAWSON, COMMISSIONER
STUART M. STATLER, COMMISSIONER
THOMAS W. MURR, JR., DIRECTOR, BUDGET PROGRAM
LEONARD DE FIORE, EXECUTIVE DIRECTOR
DANIEL R. LEVINSON, GENERAL COUNSEL

INTRODUCTORY REMARKS

Senator ABDNOR. Our next group is the Consumer Product Safety Commission.

I would ask for order, please. Those leaving will please leave quietly. We want to move right along here.

I welcome the Consumer Product Safety Commission to our hearing. I see you have the Commissioners all with you. I think there are four of you; is that right?

Mr. SCANLON. That is correct, Senator.

Senator ABDNOR. Your Budget Director and Commissioners and your General Counsel. If you wish to summarize your written statement, fine. I urge you to move right along with quick summaries, for I can assure you that the entire statement that you have will be placed in the record.

Senator LEAHY. Mr. Chairman, I wonder if I might just excuse myself. We have a matter in the Intelligence Committee that has come up and the vice chairman and I will have to go to it. I wonder if I might leave some questions with your staff to have submitted for the record?

Senator ABDNOR. Absolutely. Thank you.

Senator LEAHY. I appreciate the courtesy.

Senator ABDNOR. Chairman Scanlon, I will let you proceed in any manner you so desire.

Mr. SCANLON. Thank you, Mr. Chairman.

INTRODUCTION OF ASSOCIATES

I would like to introduce the other Commissioners, if I may. Vice Chairman Saundra Armstrong on my left; Stuart Statler and Carol Dawson. On my right is our Budget Director, Tom Murr, Len DeFiore, our Executive Director, and Dan Levinson, our General Counsel.

PREPARED STATEMENT

Mr. Chairman, thank you for giving me the opportunity to present the views of the Consumer Product Safety Commission with respect to its 1986 budget request. We have a prepared statement, but in the interest of time, let me summarize it and ask that the full text be inserted in the subcommittee record.

[The statement follows:]

STATEMENT OF CHAIRMAN TERRENCE SCANLON

Mr. Chairman and Members of the Subcommittee. I am pleased to appear before you today in my new role as Chairman of the Consumer Product Safety Commission. The Commission is charged by Congress with the responsibility for protecting the public against unreasonable risks of injury from consumer products. The Commission discharges its responsibility by developing uniform safety standards for consumer products; arranging for the recall, replacement or repair of substantial hazards; and promoting research and investigation into the causes and prevention of product-related deaths, illnesses, and injuries. Our mission is vast in scope and our agency relatively small. This year our challenge is to carry out our mandate for product safety and contribute to the efforts by the President and the Congress to trim our nation's deficit.

Budget Request

The Commission has submitted a Fiscal Year 1986 Budget Request of $33,700,000 and 568 FTE's in consonance with the Office of Management and Budget. However, this request does not include funding for programs under the Cigarette Safety Act of 1984. The Consumer Product Safety Commission has been designated the lead agency under the Act. In conjunction with the Department of Health and Human Services and the Federal Emergency Management Agency, the CPSC is charged with determining the technical and commercial feasibility of developing cigarettes and little cigars that will have a minimum propensity to ignite upholstered furniture or mattresses. The request also assumes a 5 percent across-the-board pay cut for federal employees as recommended by the President.

This request is reduced from the Commission's request of $37,350,000 and 592 FTE's submitted last October. We believe this revised request is appropriate. Our current FY 1986 budget request, which is below our appropriations levels for FY 1984 and FY 1985, is a demonstration of our intent to contribute to deficit reduction. We are confident we can absorb this reduction while continuing work toward the product safety goals set out in the original budget request. We can achieve these goals through a streamlined management system, careful targeting of priority projects, and the efforts of a dedicated staff. Improvements in the Commission's administrative structure account for much of this efficiency. Building rentals, supply management, and an increased emphasis on shifting personnel from support to hazard programs were all evaluated in light of these budgetary constraints.

Recent Accomplishments and Activities

A brief review of some of the Commission's recent accomplishments evidences our ability to use limited resources in a manner designed to make real and lasting contributions to the safety of American consumers. A good example concerns poison prevention. A recent study from Birmingham, Alabama, reveals the disturbing statistic that 36 percent of all prescription drugs swallowed by children under five involve grandparents' medication. Eager to disseminate this information as widely as possible, the Commission co-sponsored National Poison Prevention Week and used the occasion to warn both grandparents and parents of the need to employ child-resistant bottle-top closures whenever children are around.

Similarly, our findings that falls from stairs, ramps or landings are the most frequent of consumer product-related injuries, and that the elderly are often the victims of such accidents, led the Commission to launch an intensive Safety for Older Consumers campaign. This year, an illustrated "Home Safety Checklist" will be distributed to over 650 Area Agencies on Aging in the U.S. and to many national, state and local consumer agencies.

Information and education campaigns like those noted above play an important part in the Commission's activities. However, they represent only one among a number of tools used by the Commission to carry out its statutory mission. In accordance with the 1981 amendments to the Consumer Product Safety Act that require the Commission to defer to voluntary standards that adequately address identified risks of injury and that have substantial industry compliance, the Commission has been working with a wide spectrum of voluntary standards organizations, including Underwriters Laboratories, the American National Standards Institute, the American Society for Testing and Materials, and others, to encourage the development or upgrading of voluntary safety standards to address identified risks associated with a variety of consumer products. These include gas space heaters, chainsaw kickback, juvenile furniture, and riding mower stability.

While encouraging voluntary action, the Commission is not hesitant to use available mandatory methods to assure consumer product safety when circumstances require. As you are aware, we are empowered to set mandatory standards, to impose labeling and packaging requirements, and even to ban consumer products.

Further, under Section 15 of the Consumer Product Safety Act, industry must report potentially hazardous product defects to the Commission. If corrective action is warranted, the Commission urges industry to take steps voluntarily to remove the hazardous products from the marketplace before seeking compulsory remedial action. We are pleased to report that over 95 percent of these cases are settled by voluntary corrective action plans.

A notable example of a recent settlement in a Section 15 case is the agreement reached between the Commission and a major manufacturer. Under the agreement, the manufacturer agreed to undertake an extensive corrective action program to help prevent fires and explosions associated with LP gas control valves used in certain furnaces and water heaters. The Commission also negotiated a civil penalty settlement of $800,000 to resolve allegations that the firm failed to timely report to the Commission, under Section 15 of the CPSA, the existence of potential problems associated with these LP gas control valves. This is the largest civil penalty settlement in the Commission's history.

There are several other prominent examples of Commission action in correcting or removing unsafe consumer products from the marketplace in recent months. For example, in July 1984, CPSC and a company announced a corrective action program involving approximately 136,000 electric pressure washers. The Commission became aware of several fatalities caused by electric shock problems related to certain pressure washers. The firm involved offered a free repair kit that corrected the problem. The pressure washers were produced prior to mid-1983 and sold under 18 different brand names. All of the private labelers who distributed these products are participating in this program as well.

Also last July, the Commission and a manufacturer announced the recall of the cup-shaped head of a toy due to a potential suffocation hazard. A free, safer replacement was offered. CPSC was actively involved in the investigation and action which led to the recall of approximately 278,000 of these products.

Priority Projects

The Commission continuously strives to identify those products that present the most serious safety problems for consumers. Through this priority process we allocate our resources and target those areas of greatest concern. To the extent practicable, the Commission fully funds priority projects to assure that they are completed within the shortest possible time.

For Fiscal Year 1986, we adopted these five priority projects:

Electrocution Hazards. Each year more than 500 persons are electrocuted in incidents involving products under CPSC jurisdiction. In FY 1986, the Commission will conduct a consumer awareness program through participation in Electrical Safety Month; evaluate voluntary revisions that require the addition of shock protection devices; and encourage changes in the National Electric Code to expand the use of ground fault circuit interrupters--devices which detect and interrupt a potentially dangerous electrical leakage through a person's body. Increased homeowner use of this device in bathrooms, kitchens, garages, basements, workshop areas, and outdoor receptacles should reduce the incidence of electrocutions.

Fire Toxicity. Approximately 70 percent of the 4,840 deaths in residential fires occurring each year are attributable to inhalation of toxic gases rather than burns. The objective of this project is ultimately to reduce deaths and injuries resulting from the toxic combustion of consumer products.

In FY 1986, the Commission will expand its liaison activities to include Federal, state and local agencies, as well as industry, in advisory groups to coordinate joint investigative and standards-setting activities. CPSC will continue to evaluate toxicity data to make recommendations concerning modification or usage.

Gas Heating Systems. The most recent estimate indicates that about 250 carbon monoxide poisoning deaths associated with gas appliances occur in the home annually. The largest single contributor to deaths caused by carbon monoxide poisoning is vented gas-fired heaters; accidents involving these products result in an estimated 120 carbon monoxide-related deaths annually. Gas-fired heating appliances also accounted for 24,500 fires and 220 fire-related deaths in 1982.

In FY 1986, the Commission will continue efforts to encourage industry to develop and use reliable, low-cost carbon monoxide detectors and fuel gas detectors on gas-fired appliances. CPSC will recommend safety improvements to the existing voluntary standards for water heaters, flexible connectors, and gas-fired space heaters (vented and unvented).

Portable Electric Heaters. The primary hazard associated with the use of portable electric heaters is fire. An estimated 130 deaths, 370 injuries, and 3,300 fires in 1982 were associated with portable electric heaters.

In FY 1986, the Commission will participate in research and evaluation of heater designs and new technologies to reduce the fire hazard; propose and support new provisions to existing voluntary standards and State and local codes; and prepare an in-depth analysis of hazard data associated with portable electric heaters.

Riding Mowers. In 1980 an estimated 100 deaths associated with riding mowers and garden tractors. The major hazard associated with the use of riding mowers and garden tractors is blade contact. Approximately 80 percent of the fatal accidents result from three typical hazard patterns: mowers back over people; an operator or passenger falls or is thrown from mower; or a mower overturns.

In FY 1986, the Commission will continue its work with the industry in an effort to upgrade the voluntary standard for riding mowers. Human factors and engineering related contract studies will investigate riding mower stability, handling characteristics, and the potential use of warning signals and labels.

Other Safety Projects

In addition to the specifically designated priority projects, there are several other areas of concern to the Commission. The Commission works in cooperation with industry in developing safety standards and programs in many areas, a few of which are highlighted here.

The Commission will continue to monitor and evaluate potential hazards through its Fire and Thermal Burn Program. Fire deaths most often occur in the home. In 1983, there were an estimated 641,500 residential fires which caused about 4,800 deaths. Deaths in residents constitute almost 80 percent of all fire deaths. Several projects are underway to reduce this toll, including activities to lessen apparel flammability, develop and/or modify codes for wood and coal heating equipment, and assist the industry's voluntary program to reduce upholstered furniture fires.

The Emerging Hazards Program evaluates potential product hazards and identifies safety problems requiring Commission action. This program supports the Section 15 activities of the Directorate for Compliance and Administrative Litigation and supplements the other CPSC hazard programs. In addition, this program addresses new projects in their initial stages. For FY 1986, activities will center on Product Safety Assessment, New Project Identification, and Petition Evaluations and Special Projects.

The Commission is currently evaluating All Terrain Vehicles (ATVs) in the light of the most recent injury data, which indicate increasing consumer safety concerns.

Finally, Mr. Chairman, I wish to note the benefits that have accrued from the Commission's establishment of a viable state and local cooperative program. This program has greatly enhanced our Compliance and Enforcement, Hazard Identification, and Outreach activities.

In addition, a pilot import surveillance project, possibly using experienced commissioned state and local officials is being developed. This pilot effort will complement two program areas: the enforcement of mandatory standards and the monitoring of industry conformance with voluntary standards.

We believe that these activities have demonstrated a return to the Commission in terms of increased consumer safety and awareness which justifies and far outweighs the funds awarded to the participating states. This program serves to expand our efforts to alert consumers to recalls, potential hazards and other consumer awareness programs.

Conclusion

With that brief description of our programs, let me assure you that the Commission is fully committed to the task of protecting consumers from unreasonable risks of injury and insuring the most effective use of every dollar appropriated for our work.

FISCAL YEAR 1986 BUDGET REQUEST

Mr. SCANLON. The CPSC was established in 1973 as an independent regulatory agency with broad responsibility for protecting the public against unreasonable risks of injury stemming from consumer products. To do its job, the Commission has a variety of regulatory tools at its disposal, some of which will be employed in the five priority projects the Commission has adopted for fiscal year 1986.

FIVE PRIORITY PROJECTS

Those projects, which will be funded to the fullest possible extent to expedite their completion, will focus on: One, electrocution hazards, cause of over 500 deaths annually, encouraging the use of shock protection devices and ground fault circuit interrupters will be a primary objective.

Two, fire toxicity, to which almost 3,400 deaths a year have been attributed. The fiscal year 1986 focus will be on investigative and standard-setting activities in conjunction with other Federal, State, and local agencies and industry groups.

Three, gas heating systems. The most recent estimate indicates that about 250 carbon monoxide poisoning deaths associated with gas appliances occur in the home annually. The largest single contributor to deaths caused by carbon monoxide poisoning is vented gas-fired heaters. Accidents involving these products result in an estimated 120 carbon monoxide-related deaths annually. Gas-fired heating appliances also accounted for 24,500 fires, and 220 fire-related deaths in 1982.

In fiscal year 1986, the Commission will continue efforts to encourage industry to develop and use reliable, low-cost carbon monoxide detector and fuel gas detectors on gas-fired appliances.

Four, portable electric heaters, which caused 130 deaths and 370 injuries as late as 1982. Giving encouragement to the development of new heater designs and voluntary standards to govern those heaters will be one of the principal objectives.

Five, riding mowers, which are associated with an estimated 100 deaths per year. Major activities planned for 1986 include working with industry to upgrade the existing voluntary riding mower standard and studying the stability and handling characteristics of these mowers.

EMERGING HAZARDS IDENTIFIED

In addition to these priority projects, the Commission will, as part of its overall program, continue to identify emerging hazards. Of particular concern at this moment are all-terrain vehicles which we are currently evaluating in light of a sharp increase in injuries and deaths in the last 2 years. An appropriation of $33.7 million is being requested in fiscal year 1986 to carry out these and other activities.

But before I explain why we believe the Commission will be able to fulfill its responsibilities with fewer dollars than were appropriated in either fiscal year 1984 or 1985, let me give you a brief rundown on our accomplishments in the last year or so.

PAST ACCOMPLISHMENTS

They are, we believe, indicative of an ability to make even more effective use of the taxpayers' dollars in the future. In the area of consumer education, two initiatives, in particular, stand out in the terms of potential cost effectiveness. They are, first, the safety for older consumers campaign launched late last year. It has centered around distribution of a home safety checklist which, by the end of this year, will have been distributed to over 650 area agencies on aging, plus numerous National, State, and local consumer agencies and organizations.

Second, cosponsorship of National Poison Prevention Week, the publicity from which is destined to encourage parents, and especially grandparents, to keep their prescription drugs in childproof containers when young children are around.

ENFORCEMENT

With respect to enforcement, let me give you three examples of how the Commission has made its presence felt. Last July, the Commission negotiated the recall of 278,000 units of a toy which presented a potential suffocation hazard. Later that same month, we prompted another manufacturer to make a free repair kit available so that upward of 136,000 electric pressure washers could be fixed in such a way as to forestall possible electric shocks, and even more recently, the Commission entered into an agreement with a major manufacturer that will lead to the replacement of certain gas control valves that have been associated with the threat of fires and explosions.

As part of the same settlement, the Commission negotiated an $800,000 civil penalty with that manufacturer for not reporting a potential substantial product hazard. This is the largest civil penalty in CPSC's history.

BUDGET REFLECTS REDUCTION FROM FY 1985

As I mentioned previously, the majority of the Commission feels that it can fulfill its responsibilities and build upon its accomplishments with an appropriation of $33.7 million and 568 FTE's in fiscal year 1986. This figure, which is in consonance with the Office of Management and Budget, assumes a 5-percent across-the-board pay cut for Federal employees, but it does not include moneys for programs under the Cigarette Safety Act of 1984.

Also, you will note that this request is lower than the $37.35 million figure and 592 FTE's requested by the Commission last October. However, we believe we should contribute to the objective of Federal budget reductions as stipulated by both the President and Congress, and we are confident that we can do so while continuing work toward the product safety goals set out in the original budget request.

In our judgment, this objective can be achieved by means of a streamlined management system, a careful targeting of priority projects, and the efforts of a very dedicated staff.

Mr. Chairman, let me assure you that the CPSC is fully committed to the task of protecting consumers from unreasonable risk of injury in the most cost-effective manner possible. On that basis, the Commission requests that you and your colleagues give favorable and timely consideration to our $33.7 million budget request.

Mr. Chairman, I do have a personal statement which outlines many of the activities that have been accomplished in the last couple of years, particularly in the compliance area. Rather than take time, you have advised us that you have time constraints. So that I would defer to my other colleagues. I would like to have your permission to submit that into the record.

Senator ABDNOR. Without objection, that statement will be made a part of the record.

[The information follows:]

CHAIRMAN SCANLON'S PERSONAL OBSERVATIONS

In the last 11 years, over $400 million of taxpayers' money has been spent by CPSC in pursuit of consumer product safety.

The most cost-effective and balanced approach to the goal of greater consumer safety in my view is to encourage and foster meaningful voluntary standards and to actively encourage State and local governments to supplement product safety services. This is more efficient and less expensive than Federal approaches.

Achieving the goal of product safety by harboring a basic distrust of industry is outdated. I believe that the spirit of cooperation that the Congress embodied in the CPSC's mandate of 1981, that of voluntary standards first in certain circumstances before mandatory ones is the wave of the future. If we—government, industry, and the consumer movement—work together as I think we can, we may never go back to government-mandated regulations as the norm.

I would like to mention just three areas of CPSC enforcement:

1. *Civil penalties.*—Obtaining comparable or even greater enforcement results than in previous years is a challenge the CPSC has met. From March 1977 to December 1980, civil penalty actions initiated resulted in actual payment of $1,358,000. However, during a comparable 2-year period from February 1981 to March 1983, in leaner budget years and with fewer staff, enforcement activities have netted $1,304,750 from civil penalty actions initiated in this time period. Civil penalty collections have been rising steadily in the last 6 years from $20,500 in 1979 to $835,000 in 1985. Clearly, this shows that

larger budgets have not translated into greater effectiveness in the past. The Commission has intensified its focus and successfully met its enforcement responsibilities.

2. *Section 15.*—The Commission has continued to monitor industry reports of potential unsafe or defective products submitted under section 15 of the Consumer Product Safety Act. One hundred and twenty-eight reports were received in 1984. During the first 5 months of fiscal year 1985, we had already received over 100 reports.

3. *Recalls.*—In 1980, under section 15, there were 132 recall actions initiated. In fiscal year 1984, as the full effect of budget constraints were felt, the number of actions initiated fell only slightly to 106. The record is clear. We are now and can fulfill our responsibilities.

These remarks reflect my personal thoughts in addition to the Commission's own testimony.

Thank you.

STATEMENT OF SAUNDRA BROWN ARMSTRONG

PREPARED STATEMENT

Senator ABDNOR. The rest of the Commission, again, do you have statements?

Mr. SCANLON. I believe Vice Chairman Saundra Armstrong does.

Ms. ARMSTRONG. Good morning, Mr. Chairman, and members of the subcommittee. I also have a lengthy statement I would request be made part of the record. I have updated some of the information that you received on Friday, and I will leave it with staff.

Senator ABDNOR. It will be included.

[The statement follows:]

STATEMENT OF VICE CHAIRMAN SAUNDRA BROWN ARMSTRONG

Mr. Chairman and Members of the Subcommittee.

I would like to thank you for this opportunity to appear before you to testify in support of the President's 1986 budget of $33.7 million for the Consumer Product Safety Commission. I believe that we will be able to accomplish the programs and perform the functions described in our January 1985 budget request at this funding level.

In the 17 months that I have served as a member of the Commission, there have been continuing efforts to streamline our operations, control spending, and sharpen the focus of our programs. This has been done largely by concentrating our resources in areas which are designated as priorities (with the concurrence of this Subcommittee), which are determined to constitute immediate needs or major health and safety problems, and which will provide the greatest protection and benefits to American consumers. While the current request level represents approximately a 10 percent decrease from our October, 1984, budget submission to this Subcommittee, I supported this reduction because I considered it appropriate in view of the intensified efforts by the President and Congress to reduce the national deficit.

The Commission's January budget request, which corresponds with the funding level which was approved and presented to this Subcommittee by the Office of Management and Budget, would enable the Commission to continue to operate at its on-board strength, as of January 1985. With an equivalent complement of dedicated professional, technical, and support staff, I believe that we can continue to operate and discharge our statutory responsibilities at a level which is consistent with the last two fiscal years. However, it should be pointed out that our Fiscal Year 1986 budget request does not include an appropriation request for the research and other activities required by the Cigarette Safety Act. At this time, it is our intention, as the designated lead agency for the interagency committee, to request a supplemental appropriation in the current fiscal year to cover the projected expenses of the technical study group.

Our program plans for Fiscal Year 1986 reflect several Commission initiatives which demonstrate a continuing commitment to fulfill our mandate to protect American consumers from unreasonable risks of injury associated with consumer products and to effectuate our statutory responsibilities. In my statement this morning, I will briefly summarize some of these initiatives and accomplishments.

Continuing Emphasis on Voluntary and Cooperative Efforts

In accomplishing the objectives of our priority projects and on-going hazard programs, we have in the past, and will continue in the next fiscal year, to work closely with industry and consumer groups, state and local governments, the voluntary standards community, and other Federal agencies. Through voluntary and cooperative efforts, we can leverage our capabilities and resources to achieve a potentially greater positive impact in resolving consumer safety problems and issues; and we can mitigate any adverse economic effects on business and consumers.

Since its inception, the Commission has participated with private sector organizations in over 130 voluntary efforts. These projects have resulted in the publication of about 75 new voluntary standards and upgraded revisions of about 25 others. The scope of the Commission's commitment to voluntary standards is clear when we realize that during the Agency's 12-year history, only 35 mandatory standards or banning rules have been issued. In the current fiscal year, the Commission has allocated 48.5 percent of its hazard program resources (which includes both staff salaries and contract dollars) to the support of voluntary efforts. For Fiscal Year 1986, the Commission will meet or exceed the FY 1985 allocation.

I personally believe that mandatory and voluntary standards serve important purposes, and both tools are, in my estimation, indispensable to effectuation of our Congressional mandate of protecting the public against unreasonable risks of injury associated with consumer products. I perceive the voluntary standards process as positive because its essence is the cooperative association of different groups, effectively coping with a diversity of interests and harmonizing them to produce a product standard of benefit to industry, the government, and the consumer.

In the next fiscal year we will continue and, in some cases, broaden voluntary activities and approaches which have been demonstrably effective in past fiscal years. Some positive indicators of the success of these efforts are:

-- Expanded dialogue and more joint activities with voluntary standards-setting organizations and trade associations to address consumer safety issues.

-- Appointment of a full-time voluntary standards coordinator.

In the current fiscal year, the Commission and the staff conducted and participated in numerous meetings with major industry and consumer groups to discuss consumer safety issues ranging from chain saws to first aid labeling to all terrain vehicles. In addition, several joint conferences with industry will be conducted in the coming months focusing on poison prevention packaging; pool and spa safety and drowning prevention; and safety for older consumers.

In Fiscal Year 1986, we plan to continue this thrust. We will present regional seminars for manufacturers, retailers, and distributors on Section 15 reporting requirements. We will also continue to play an active role in the voluntary standards process by participating in or monitoring industry committee work in developing or revising existing standards where we believe a product hazard exists.

Program plans for Fiscal Year 1986 also indicate other intended uses of cooperative approaches in discharing our statutory compliance and enforcement responsibilities. For example, a total of $250 thousand ($150 thousand more than in FY 85) has been allocated to fund a larger number of agreements with state and local health and safety agencies (e.g., fire departments, health departments, consumer protection/affairs agencies, and coroners) and to acquire additional support and assistance through the network of Cooperative Extension Service agencies. These agreements will support an expanded five-point program which will be administered by the Directorate of Field Operations. The program is intended to augment the Commission's capability in the areas of:

- Source development and investigation;
- Enforcement of certain mandatory standards (toys, children's products, refuse bins, fireworks, architectural glazing, household chemicals, and certain regulations under the Flammable Fabrics Act);
- Monitoring industry conformance with certain voluntary standards (upholstered furniture, garage door openers, electric blankets, and unvented gas space heaters);
- Outreach and dissemination of product safety information; and
- Import surveillance.

Increased Capacity for Identification of Emerging Hazards and Product Assessment

Significant corollaries to our greater emphasis on voluntary and cooperative efforts are:

- We are given access to more sources of product incident data, information about potentially hazardous products, and violations of mandatory and voluntary standards; and
- We have more non-Federal intermediaries who can serve as conduits in providing information to consumers and who can interact with and assist them directly.

Thus, our increased cooperation with public and private sector organizations at the state and local level in FY 86 will substantially broaden our capabilities in identifying emerging hazards; in providing timely notification to the public, manufacturers, distributors, and retailers concerning hazardous products; and in conducting routine investigations as well as special research.

Fiscal Year 1986 is the point at which our intensified compliance and enforcement efforts (FY 85) and enhanced state and local cooperative efforts (FY 86) will converge. We expect that the increase in inspections and sample collection as a result of these initiatives will create a greater demand for product safety assessment and analysis by our engineering staff. Moreover, we anticipate that the advent of microelectronics will require the Commission to have, in the not too distant future, greater capability in evaluating consumer products which are based on this new technology. In view of these circumstances, 2.0 additional full-time equivalents (FTEs) */ have been assigned to the Directorate of Engineering in FY 86. One position has been designated for an engineer who has a specialization in microcircuitry.

Safety for Older Consumers: A Model of Cooperation

I mention the Commission's "Safety for Older Consumers" priority project because, in my opinion, it cogently demonstrates the benefits as well as the economies that can be derived from cooperative efforts.

While the safety of the elderly is an on-going consideration of the Commission, the particular vulnerability of older persons to injury or death caused by accidents in the home is a source of growing national concern. This year an unprecedented number of Americans -- a total of 28 million -- will be age 65 or over. The United States Census Bureau predicts that the growth trend we are witnessing in our Nation's elderly population will continue through the middle of the next century. As the post-World War II cohort ages, the number of injuries and deaths due to accidents in the home could rise dramatically.

Out of concern for the personal devastation to the elderly caused by home-related accidents, and the attendant implication that such injuries will demand an even greater share of our Nation's health care resources as the size of our elderly population increases, the Consumer Product Safety Commission established "Safety for Older Consumers" as a priority project in Fiscal Years 1984 and 1985 to increase awareness of this major public health concern.

This Commission priority project is mainly intended to serve as a catalyst for on-going public and private sector initiatives to prevent accidental injuries and deaths among the elderly. In the coming months, we will be working with national, state, and local organizations to disseminate a Home Safety Checklist (developed through the auspices of the "Safety for Older Consumers" priority project) as widely as possible and to conduct public awareness activities.

Already, 32 states and the District of Columbia, 8 cities, and 9 county and regional agencies have indicated their support for the project and informed us of plans to conduct programs and activities related to "Safety for Older Consumers" within their jurisdictions. In addition, we have cooperative efforts underway with over 30 national organizations and several corporations to distribute the Home Safety Checklist. **/ I will be meeting in the

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*/ Two full-time equivalents above the current on-board strength of 63.7 FTEs.

**/ See attachment

near future with representatives of two trade associations which represent major gas and electric utility companies in the country to explore the possibility of collaborative efforts.

The "Safety for Older Consumers" project is also being significantly advanced through interagency relationships which have been established with the Departments of Health and Human Services, Housing and Urban Development, and the Treasury; the United States Office of Consumer Affairs; and the Veterans Administration. The Department of Agriculture has also expressed support for the project.

There are several significant factors underlying the success and effectiveness of this consumer safety initiative. The most obvious of these is that the project addresses a growing public concern. A second key factor is that in promoting the project, we succeeded in tapping and receiving almost unanimous support from a vast network of agencies which are the principal service providers for the target population. Finally, the pilot tests and the evaluation confirmed that the project is highly replicable and that it can be easily integrated into existing service delivery programs for the elderly with a minimal investment of resources.

In summary, the "Safety for Older Consumers" priority project provides a successful demonstration of what can be achieved with relatively modest resources and through the strategic and persistent application of numerous and diverse cooperative approaches (in this case, "peers helping peers"; Federal, state and local cooperation; joint public and private sector initiatives; and collaboration among Federal government agencies(to achieve mutual and compatible consumer product safety goals.

Improved Organizational Environment and Better Use of Resources

At my initiative, the Commission will begin a comprehensive management analysis within the next few months. With a team of management experts, we will conduct an intensive review and analysis of our organizational structure, management systems, and operations to determine how we can deploy our resources more effectively and efficiently while fulfilling our statutory mandate and responsibilities. We expect the analysis to result in a number of improvements which should significantly facilitate the implementation of our Fiscal Year 1986 program plans within the parameters of the resource requirements delineated in our January budget submission.

Among other things, the management analysis will include:

- a detailed review of the current matrix management system;
- an analysis of the agency's long-term research activities, their actual and projected costs, and the benefits and results which are likely to be derived from them in light of our mandated objectives and functions and our austere fiscal condition; and

- a review of the field structure, operations, and staffing as well as the productivity of this contingent in view of the accountability framework within which it operates.

Conclusion

Admittedly, it is a challenge to effectively and consistently implement the intent of Congress through programs and operations which must continue to exist in a more rigorously managed organizational environment and with leaner resources. Nevertheless, I believe that with the results-oriented program plan which we have developed, a heightened sense of fiscal responsibility engendered by government-wide budget constraints, and our relentless pursuit of voluntary and cooperative approaches to address safety problems and issues, this Commission can continue to meet the major consumer product safety needs of this Nation.

In this context, I intend to lend my full support to the implementation of this budget and other directives given to this Commission by Congress.

I will be happy to provide any additional information you might require concerning my remarks and to respond to your questions at this time or later in writing.

Thank you.

ATTACHMENT TO STATEMENT OF SAUNDRA BROWN ARMSTRONG

Safety for Older Consumers

A. States, cities, counties and regional organizations which are supporting and/or implementing the program. (* denotes those which have been awarded purchase orders from CPSC.)

States (33)

1. Pennsylvania
2. California
*3. Louisiana
*4. Connecticut
*5. New Hampshire
*6. Rhode Island
*7. Idaho
*8. Wyoming
*9. Indiana
*10. Michigan
*11. Nebraska
*12. Illinois
*13. Wisconsin
*14. Iowa
*15. North Dakota
*16. South Dakota
*17. Minnesota
*18. Ohio
*19. Georgia
20. Alabama
21. South Carolina
22. Florida
23. West Virginia
24. Tennessee
25. Virginia
26. Arkansas
27. New Mexico
28. Texas
29. Oklahoma
30. Washington
31. Oregon
32. Hawaii
33. District of Columbia

Cities (8)

*1. Philadelphia, PA
*2. Allentown, PA
*3. Baltimore, MD
*4. Albuquerque, NM
*5. Bakersfield, CA
*6. Birmingham, AL
7. Houston, TX
8. Los Angeles, CA

County/Regional (9)

1. Morris County, NJ
*2. Burlington County, NJ
*3. Clackamas County, OR
*4. Tacoma/Pierce County, WA
*5. Broward County, FL
*6. Blue Grass Area Agency on Aging
*7. North Central Texas Area Agency on Aging
*8. Denver Area Agency on Aging
*9. Oklahoma City Areawide Aging Agency

B. Sample listing of organizations/associations which are assisting with the distribution of the Home Safety Checklist and promotion of the program.

1. American Medical Association
2. American Association of Retired Persons
3. National Safety Council
4. Gray Panthers
5. National Association of Retired Federal Employees
6. Gerontological Society of America
7. Older Women's League
8. American Institute of Architecture
9. Alliance of American Insurers
10. National Association of Counties
11. National Caucus and Center for the Black Aged
12. National Council on Aging
13. Consumer Federation of America
14. National Association of State Units on Aging
15. American Foundation for the Blind
16. ANSI
17. ASTM

C. Assistance provided by other Federal Agencies:

- Department of Health and Human Services. Printing one million additional copies of the Home Safety Checklist which will be distributed by the Administration on Aging to the 660 Area Agencies on Aging. Support has also been expressed by NIH, the Center for Disease Control, Office of the Surgeon General, and the Public Health Service.

- U.S. Office of Consumer Affairs. Newsletter article; general support; participation in national conference.

- Department of Housing and Urban Development. Will distribute the Checklist through their network of local coordinators of public housing projects for the elderly and through their regional offices; newsletter article.

- Department of Agriculture. Will send copies of the Checklist to their Cooperative Extension Service staff.

- Department of the Treasury. Will print notice concerning the availability of Checklist at Area Agencies on Aging on envelopes of May social security checks.

- Veterans Administration. Will send copies of the Checklist to all 172 VA medical centers.

SUMMARY OF STATEMENT

Ms. ARMSTRONG. I would like to thank you for this opportunity to appear before you to testify in support of the President's 1986 budget of $33.7 million for the Consumer Product Safety Commission. I believe that we will be able to accomplish the programs and perform the functions described in our January 1985 budget request at this funding level.

In the 17 months that I have served as a member of the Commission, there have been continuing efforts to streamline our operations, control spending, and sharpen the focus of our programs. This has been done largely by concentrating our resources in areas which are designated as priorities, which are determined to constitute immediate needs or major health and safety problems, and which will provide the greatest protection and benefits to American consumers.

BUDGET REDUCTION SUPPORTED

While the current request level represents an approximately 10 percent decrease from our October 1984 budget submission to this subcommittee, I supported this reduction because I consider it appropriate in view of the intensified efforts by the President and Congress to reduce the national deficit.

The Commission's January budget request, which corresponds with the funding level which was approved and presented to the subcommittee by the Office of Management and Budget, would enable the Commission to continue to operate at its on-board strength as of January 1985.

Our program plans for fiscal year 1986 reflect several Commission initiatives which demonstrate a continuing commitment to fulfill our mandate to protect American consumers from unreasonable risks of injury associated with consumer products and to effectuate our statutory responsibilities.

INITIATIVES AND ACCOMPLISHMENTS

In my statement this morning, I will very briefly summarize some of these initiatives and accomplishments.

First, there is a continuing emphasis on voluntary and cooperative efforts. In accomplishing the objectives of our priority projects and ongoing hazard programs, we have, in the past, and will continue in the next fiscal year, to work closely with industry and consumer groups, State and local governments, the voluntary standards community, and other Federal agencies. In fiscal year 1986 we will present regional seminars for manufacturers, retailers, and distributors of consumer products regarding their section 15 reporting requirements. We will also continue to play an active role in the voluntary standards process by participating in or monitoring industry committee work to develop or revise existing standards where we believe a hazard exists.

In addition, a total of $250,000—$150,000 more than in fiscal year 1985—has been allocated to fund a larger number of agreements with State and local health and safety agencies and to acquire additional support and assistance through the network of the cooperative extension service agencies.

INCREASED COOPERATION BROADENS CAPABILITIES

Our increased cooperation with public and private sector organizations at the State and local level in fiscal year 1986 will substantially broaden our capabilities: one, in identifying emerging hazards; two, in providing timely notification to the public, manufacturers, distributors, and retailers concerning hazardous products; and, three, in conducting routine investigations as well as special research.

Fiscal year 1986 is a point at which our intensified compliance and enforcement efforts from fiscal year 1985 and enhanced State and local cooperative efforts of fiscal year 1986 will converge.

We expect that the increase in inspection and sample collection as a result of these initiatives will create a greater demand for product safety assessment and analysis by engineering staff. Moreover, we anticipate that the advent of microelectronics will require the Commission to have, in the not too distant future, greater capability in evaluating consumer products which are based on this new technology. In view of these circumstances, two full-time equivalents have been assigned to the directorate of engineering for fiscal year 1986. One position has been designated for an engineer who has a specialization in microcircuitry.

SAFETY FOR OLDER CONSUMERS

A model of cooperation. I mention the Commission's safety for older consumers priority project because, in my opinion, it demonstrates the benefits as well as the economies that can be derived from cooperative efforts. While the safety of the elderly is an ongoing consideration of the Commission, the particular vulnerability of older persons to injury or death caused by accidents in the home is a source of growing national concern. Each year more than 600,000 people over the age of 55 are treated in hospital emergency rooms for injuries associated with products in their homes. Moreover, it is estimated that the cost of medically attended injuries of this age group in 1983 was $3 billion.

The Commission's safety for older consumers priority project is mainly intended to serve as a catalyst for ongoing public and private sector initiatives to prevent accidental injuries and death among the elderly. Already, 32 States and the District of Columbia, 8 cities, and 9 county or regional agencies have indicated their support for the project and informed us of plans to conduct programs and activities related to the Safety for Older Consumers Program within their jurisdictions.

In addition, we have cooperative efforts underway with over 30 national organizations and several corporations to distribute the home safety checklist.

Senator ABDNOR. Ms. Armstrong, I don't like to rush you, but can you kindly summarize that? We have to move along. We have another Commissioner, and if I leave, we will have to stop the meeting. I hate to do this to you, but I think you have several more pages. The whole thing will be placed in the record here. I would appreciate it if you could summarize it.

Ms. ARMSTRONG. I will summarize the remainder.

In addition to what I have just indicated concerning safety for older consumers, I will be meeting with representatives of major gas and electric utility companies to explore the possibility of their participating in cooperative efforts.

COMPREHENSIVE MANAGEMENT ANALYSIS

In addition, the Commission, at my initiative, is about to begin a comprehensive management analysis which I think will address many of the concerns that have been discussed by this subcommittee as well as other congressional representatives.

In conclusion, I will just say that it is a challenge to effectively and consistently implement the intent of Congress through programs and operations which must continue to exist in a more rigorously managed organizational environment and with leaner resources. Nevertheless, I accept this challenge; and I believe the Commission can, with the resources that we are requesting, accomplish all of the objectives and programs that we have delineated in our January 1985 submission to you.

At this point, I would be happy to respond to any questions at this time or later in writing.

Senator ABDNOR. Thank you, Vice Chairman Armstrong. I hate to rush everyone along.

STATEMENT OF STUART M. STATLER

PREPARED STATEMENT

Commissioner Statler, do you have a statement?

Mr. STATLER. Yes, Mr. Chairman. I have submitted a letter to Chairman Garn of about seven pages, and I would ask that to be included in the record, together with my official statement.

Senator ABDNOR. It is my understanding it will be.

[The statement and correspondence follow:]

STATEMENT OF COMMISSIONER STUART M. STATLER *

In the face of whopping budget deficits confronting the Nation, the current Administration's desire to reduce federal spending is understandable. What's not understandable is its determination that the Consumer Product Safety Commission shoulder a disproportionate share of the burden. In the end, it's terribly unfair for the thousands of future victims of dangerous consumer products whom we are increasingly unable to protect adequately.

CPSC's budget and staffing have been steadily eroding in recent years. Taking inflation into account, the budget imposed by OMB for FY '86 represents a decrease in real dollars, compared to our start-up in FY '74, of 53%! No other federal health or safety regulatory agency comes anywhere close to this precipitous decline. In fact, EPA's budget has jumped 87% during the same period and OSHA's has risen 32%.

It's an affront to the expectations of all Americans when OMB expects us to spend, in terms of 1974 dollars, only $14,690,000 next year to attempt to reduce the hazards that cause innumerable fires, electrocutions, asphyxiations, poisonings, cancers and other product-related calamities that beset our citizens in their everyday lives. The 15,000 products under our jurisdiction kill three Americans every hour of every day, and 3700 others are seriously injured hourly. Yet CPSC's budget and staff sink lower with each passing year.

Further analysis presents a similarly bleak picture. Adjusting for inflation, compared to our current FY '85 funding level, the FY '86 budget is down 10%; compared to our funding level just 5 years ago in FY '81 (before the start of this Administration), our FY '86 budget is down a whopping 36%.

The past 5 years also evidence the evisceration of CPSC's staff. The OMB-imposed level of 568 FTE's for FY '86 also represents a 36% swipe since FY '81, when 889 FTE's were onboard. The bottom line is ominous--both staff and funding have been slashed over one-third during this period!

Let me focus on just one glaring illustration of our budgetary crisis: With virtually all of our dollars and staff time already committed for FY '85 and '86, we've recently identified one of the most dramatic surges in deaths and serious injuries that this agency has ever witnessed. It involves 3-wheel all-terrain vehicles, or ATVs as they're called. Serious injuries have jumped nearly eight-fold in the last three years from 8,585 in 1982, to 27,534 in 1983, to 66,956 in 1984. We know of 104 ATV-related deaths during the same period, and we know

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* This statement is meant to be read in conjunction with the Commissioner's detailed letter to Chairman Jake Garn of March 22, 1985.

the figure for 1984 is incomplete at that. Most disturbing is that 46 of these fatalities (44%) were to kids under 16, and some were as young as 4-7 years of age. To make matters worse, skyrocketing sales are putting thousands more ATVs onto the marketplace every week, with sales of 780,000 expected in 1985, up from 650,000 last year and 136,000 just five years ago. For years we have used hospital emergency room reports and other statistical tools to stay on top of emerging hazards. Now having identified ATVs as perhaps the most urgent "blip" ever to appear on our hazard screen, we're poised to swing into action. But to do that means we must first decide what other worthy projects need be dropped or delayed in order to "free up" resources for the pressing ATV work.

Surely, Congress envisioned something other when it created CPSC 12 years ago. The Commission is the only agency in all of the Federal Government with the responsibility under law to do something about this ever-worsening problem. What we decide will determine, literally, how many thousands of youngsters and others will be saved from serious injury, paralysis, and death over the months immediately ahead and long into the future . . . and how many will not!

The problem goes much beyond ATVs. Dozens of our current projects are delayed or can't get off the ground, thus needlessly risking the lives of unsuspecting American families. Many other deserving projects were scrapped before even making it into our original, austere budget submission for FY '86 of $37,350,000 and 592 FTE's. This didn't happen because they lacked worth or because they wouldn't save a good number of lives.

It happened only because our agency has been underfunded and understaffed since 1981 when we had nearly 900 FTE's and a budget exceeding $42 million--a far cry from the 568 FTE's and $33.7 million proposed for next year . . . and a farther cry still from the callous figures of 440 FTE's and $25 million originally recommended by OMB. The budget people at OMB seem ideologically opposed to doing anything in this area other than redesigning the behavior of consumers rather than, where appropriate, redesigning hazards out of the products.

The worthy projects on our cutting room floor range from reducing child drownings and diving tragedies in swimming pools to cutting back on airborne microbes that can infest the heating and cooling systems of our homes; from correcting the explosion risk from damaged flexible connectors in gas appliances to determining why some circuit breakers fail to "trip" and prevent home fires and electrocutions; from minimizing the disfiguring burns caused by electric deep-fat fryers to averting the tragic crunching of youngsters by unyielding automatic garage doors.

These projects aren't found in our budget, but the risks associated with them abound in our homes, causing death, serious illness and injury, and wholesale property destruction. The projects aren't drawn from some pie-in-the-sky wish list--they're basic to our operation, because the risks are ever-present. We wish they weren't in such abundance, but they are.

At the rate we're going, the CPSC can be nickeled and dimed -- 5% here, 10% there -- for a few more years before we're so emasculated we won't be able to do meaningful safety work on any project. Only this Committee is in a position to prevent that. Only this Committee can reverse the erosion of fundamental protection against risks around the home that the American public rightfully expects and deserves.

* * * *

March 22, 1985

The Honorable Jake Garn
Chairman
Subcommittee on HUD-Independent Agencies
  of the Committee on Appropriations
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

As noted on the signature page of our January 1985 Budget Request for FY '86, my oath of office as a Commissioner of this agency compels me to submit this separate statement pointing out the inadequacy of that request. In recent years, the Consumer Product Safety Commission has been enduring sizeable personnel reductions and budget cutbacks. To fulfill our mandate from Congress, the proposed OMB budget mark of $33.7 million (and personnel ceiling of 568 FTE's) will prevent us from doing justice to the goal of protecting American citizens from death and serious injuries caused by unreasonably dangerous consumer products.

To carry out this mandate during the upcoming fiscal year, the Commission's original, carefully assembled and admittedly austere submission of $37,350,000 (and 592 FTE's), really amounts to a floor. While hardly ideal, it would at least permit us to accord to American citizens, including the particularly vulnerable populations of children and the elderly, something akin to the degree of protection they expect and deserve.

If any "fat" *ever* existed in CPSC's budget, there is certainly none now and hasn't been in recent years. Our first annual budget, in FY 1974, was $30,900,000. Now 12 years later, the amount proposed for FY 1986 represents a *decrease* in real dollar terms of 53 percent! Over the same period, no other federal health and safety regulatory agency has sustained comparable cuts. The following chart demonstrates this fact all too clearly:

Agency	FY'74 Funds	FY'86 Funds	FY'86 Funds Converted to FY'74 Dollars	% Increase or Decrease
EPA	528,000,000	2,268,000,000	988,666,000	+87%
OSHA	70,408,000	213,059,000	92,877,000	+32%
FDA	160,590,000	409,072,000	178,323,000	+11%
FTC	32,334,000	63,934,000	27,870,000	-14%
NHTSA	142,715,000	245,500,000	107,018,000	-25%
**CPSC	30,900,000	33,700,000	14,690,000	-53%**

Further analysis presents a similarly bleak picture. Adjusting for inflation, compared to our current FY '85 funding level, the FY '86 budget is down 10%; compared to our funding level just 5 years ago in FY '81, before the start of this Administration, our FY '86 budget is down a whopping 36%. The past 5 years also have witnessed the evisceration of the Commission's staff. The OMB-imposed level of 568 FTE's for FY '86 represents a 36% cut since FY'81, when 889 FTE's were onboard. The bottom line is ominous--both staff and funding have been slashed over one-third during this period!

To comply with the Budget and Accounting Act and comport with OMB's mark for FY 1986, the Commissioners, of necessity, trimmed the agency's original budget submission. As a result, dozens of our projects will be deferred or deleted. This will translate, in no uncertain terms, into tragedy and trauma for many American citizens who could have been spared. A few examples will suggest what our dollar and staff drain means in real-life human terms:

All-Terrain Vehicles (ATV's)

While three-wheeled all-terrain vehicles (ATVs) are soaring in popularity, their injury and death rates are escalating to an even greater degree. Injuries treated in hospitals increased nine-fold between 1979 and 1983, from under 3,000 to over 27,000. Then in 1984 the figure jumped to 66,956 such injuries. We already know of 104 deaths over the last three years, and the toll for 1984 (48 victims) is still very incomplete. And sadly, young children are bearing the brunt: three-fourths of the victims in ATV-related incidents are between the ages of 5 and 24, and nearly one-third are under 15. The vehicles look stable enough, but they flip over, roll over and tip over much easier than a rider or parent would expect--especially a youngster who is ill-prepared to appreciate the degree of risk or lacking in training or agility to guard against it.

As the tragedies mount, sales are skyrocketing. Sales rose nearly five-fold in the last 5 years, from 136,000 vehicles in 1980 to 650,000 in 1984. Our staff estimates that 780,000 ATVs may be sold in 1985. Today there are about 1.8 million ATVs in use in the U.S.; by the end of 1985, 2.5 million may be in use. This escalating popularity, coupled with spiralling reports of ATV instability and loss of control, requires us as a regulatory agency to press forward quickly to avert further tragic loss. Yet, our proposed FY 1986 budget contains no time or money for an ATV project.

CPSC efforts could be instrumental in dealing with the emerging ATV hazard, but we're caught between a rock and a hard place. The necessary work demands considerable engineering and compliance staff time, hazard analysis and contract dollars, especially for testing. As long as we can't spare time and money from other vital projects, we're virtually powerless to address these risks and the startling surge in injuries and deaths. And if we do tackle the problem, many other worthwhile endeavors will languish because of OMB's budgetary axe.

The Commission is the only agency in all of the Federal Government with the responsibility under law to do something about this urgent problem. What we decide will determine, literally, how many thousands of youngsters and others will be saved from serious injury, paralysis, and death...and how many will not, over the months immediately ahead and long into the future.

Drownings, Diving and Entrapment Risks

Every year more than 300 children under age 5--two children every day during the peak swimming season--drown in backyard swimming pools, spas and hot tubs. 2,000 more are treated in hospital emergency rooms. And, for every toddler who drowns, there are parents who face a lifetime of anguish and self-guilt, often blaming themselves for not adequately supervising their child.

CPSC had planned to analyze child drownings and prepare recommendations to parents based on the most common factors contributing to these tragedies. But due to OMB's budget cuts, critical underlying technical work and evaluations must be dropped. We also planned to examine the effects of fencing, pool covers and alarms to prevent drownings. Without our involvement, these safety approaches--designed as back-up systems for parental supervision--will likely founder. Additionally, we anticipated doing something to prevent any more disembowelments to kids under 6 in the drains of public wading pools--a nightmarish hazard that has killed and severely disabled numerous youngsters.

Even older children do not escape pool and spa risks: Two pre-teen girls drowned, and nine others nearly did, when their hair became entrapped in the extreme suction force created by single drains in spas. Four pre-teen boys drowned and 11 others suffered "near-misses" when parts of their bodies became entrapped in spas. 200 young adults every year, mostly males aged 18-25, tragically become quadriplegics in the prime of lives in residential pool diving incidents.

Our ability to address each of these serious drowning, diving and entrapment risks is stalled for lack of available funds and staff.

Airborne Microbes

From staff research, we know that airborne microbes are released into the air we breathe every day in our homes. Sources are such seemingly innocuous products as humidifiers, cool mist vaporizers, shower heads and forced-air heating/cooling systems. These invisible microbes can be allergens or pathogens. For that large segment of our population that spends as much as 90% of their time at home indoors--young children, the elderly, the ill and infirm-- these microscopic organisms can cause asthma, rhinitis, pneumonitis, infectious pulmonary disease, and hypersensitive reactions.

We need only recall the Legionnaire's epidemic in Philadelphia some years back. Deadly microbes can quickly and indiscriminately invade our homes and environments, and our bodies. The battle to control them, once released, has the makings of a science fiction horror movie, except that the deaths and injuries are all too real. The task before us demands highly-complex solutions, based on solid laboratory and field testing. But, under OMB's proposed funding of this agency, resources are unavailable.

Flexible Gas Connectors

Flexible gas connectors are corrugated gas tubes that connect gas ranges and other gas appliances to supply lines. Powerful gas explosions can instantly level a two-story house. Accompanying fire will destroy what's left. A cracked connector, whether originally installed that way or becoming so over time, is like having a time bomb in your home.

An industry source tipped us off that cracks might develop in these connectors when coiled into packages for retail sale. We tested 24 samples, collected nationwide, and found that 10 of them flunked. These represented the connectors of all six manufacturers! And some cracks were found where the connectors hadn't even been coiled. Our staff needs to assess the manufacturing, quality control, inspection, testing, and packaging procedures of each manufacturer. Absent this effort, due to budget and staffing constraints, cracks may only be discovered too late--when some insurance investigator sifts through charred rubble that was once a house but is no more.

Residential Sprinklers

Fire is the second leading cause of death in American homes. Since our inception, the Commission has focused substantial efforts on reducing the tragic toll of victims. But more attention is needed. One of the most promising recent developments is the proven effectiveness of home sprinkler systems. Such systems were previously more or less limited to hotels, motels, institutions and commercial settings. The U.S. Fire Administration has shown that they are also spectacularly successful in controlling the spread of fires in homes. But there's a need for monitoring new units coming onto the market, and CPSC staff should be lending its expertise. We could also inform consumers that sprinkler protection is cost-effective. And we could work hand-in-hand with insurance companies to promote premium rebates.

To encourage acceptance of home sprinklers by consumers, home builders and developers alike, for both new construction and retrofits of existing homes, the dramatic lesson of smoke detectors must be relearned. But here the initial cost outlay is much greater than for smoke detectors. Today, a 2,000 square foot new home can be protected by a system costing $1,500 to $2,000, and a comparable older home can be retrofitted for about 50 percent more.

Through funding for this project, sprinklers would be appearing in ever-increasing numbers in single-family homes, in apartment houses, in hotels and in every type of residence where potential victims reside. The pressing need is to let the American public know more about the tremendous protection now available from residential sprinklers, so that an informed choice is possible.

* * * *

OTHER HAZARDS REMAINING UNADDRESSED

During most of the past decade, the Commission was in the thick of every significant effort to protect consumers from hazards that fall within our jurisdiction. But in recent years, I'm distressed to find ourselves increasingly standing on the sidelines while critical risks are left unaddressed. This is not from lack of concern or interest, but simply from lack of adequate funds and manpower. The situation forces us to fall short of fulfilling our vital responsibilities to Congress and to the American people. Time and again we must forego vital research and enforcement activities, as demonstrated by the hazard projects noted above, and so many more. For example:

o Evidence shows that innumerable residential fires--resulting in the deaths of unsuspecting family members--are caused each year by circuit breakers that fail to "trip" when there is overloading or a defect in a home's electrical system. Circuit breaker boxes and panelboards need to be analyzed and tested to pinpoint the precise hazards, so that the results of such studies can be shared with Underwriters Laboratories (UL) and the industry. Absent such work, the risk won't go away on its own, and homes will continue to be reduced to embers.

o Youngsters too often activate an automatic garage door opener and then try to outrace the door before it slams shut. Tragically, we know of 35 children--mostly under 10 years of age--who have lost this tantalizing "game" and their lives since 1970, crushed by the unyielding door. The Commission's staff has considered low-cost ways to reduce this risk for those several million doors installed before an upgraded standard took effect in 1982. But we can spare neither the time nor funds in the budget as submitted, even to pursue these ideas with the industry.

o The chemical toluene, widely used in paints and lacquers, preliminarily has been found to be carcinogenic. For the staff and Commission to spell out the exposure risk to consumers, laboratory testing and modeling is critically needed. With funding and staff levels so decimated, we can't even approach this task.

o Chlorinated benzenes are found in mothballs, household air fresheners and diaper pail deodorizers. 450,000,000 pounds of them were produced in the U.S. in 1983 alone. With troublesome evidence in hand that at least one member of this chemical family causes devastating lymphoid leukemia and bone marrow cancer, budget restraints make it impossible for the staff even to investigate this risk.

o The application of microelectronic and computer chip technology to such power workshop tools as drills and circular saws could significantly reduce the 275,000 medically-attended injuries and 57 deaths associated with them in one recent year. For lack of resources, we had to scratch a planned staff project on the feasibility of safety features that incorporate such technology.

o Children should never be in the vicinity of electric deep-fat fryers, but four we know of have died when 400-degree cooking oil splashed or spilled on them. A great many other youngsters, and elderly citizens as well, have been disfigured from burns. According to an outside contractor's report, the existing UL standard is woefully inadequate. Its stability requirements need upgrading and it lacks provisions for other built-in protective features that could be added at very little, if any, added cost. Current budget limitations prevent our staff from analyzing or testing these deep-fat fryers, so planned efforts at improving the product are stymied.

o Textile finishes and flame retardants are a proven source of adverse health effects. Planned tests to determine how much is extracted from garments and absorbed through the skin can't be carried out on schedule at the proposed budget mark.

o Millions of consumers are placed at risk by formaldehyde emissions from particleboard, wall paneling and medium-density fiberboard made with U.F. resins. A

Department of Housing and Urban Development standard addressing this risk in mobile homes merely reflects the status quo. Our staff had been working on a much-needed, technology-forcing standard, but budget limitations will not even permit us, as planned, to measure formaldehyde levels in actual homes.

o Early detection of risks is critical in protecting against devastating home hazards. Smoke and fire alarms are widely used, but rarely such other available devices as gas and carbon monoxide detectors, shock protection devices, swimming pool alarms, etc. Recent advances in electronic circuitry permit integrating sensors for many diverse hazards. The Commission staff is ideally suited by way of background and expertise to evaluate their technical feasibility and effectiveness for use in home alarm systems. We've joined industry at the brink of a potential safety breakthrough. All that stops us is the very real and disconcerting fact that there's no room for this kind of preventive effort in the budget you have before you, which has been pared down to meet OMB's arbitrary budget mark.

o To maintain a valid data base for deaths and injuries from products, the staff should perform at least a hundred more on-site investigations of incidents involving selected consumer products. We can't do that under the OMB staffing and budget marks. We also need to purchase additional reports of medical examiners on deaths from consumer products and to pursue alternative data sources to the existing National Electronic Injury Surveillance System. We won't be able to do either, even though a crucial starting point for all standards work and recall activities is solid epidemiological data.

* * * *

CONCLUSION

When an emergency risk or hazard reaches severe proportions, the CPSC must act quickly and directly to eliminate or reduce it. Over the years, we have done so, effectively, when citizens were imperiled by TRIS in children's pajamas, asbestos in hairdryers, strangulations in cribs, fires from kerosene heaters, explosions from gas furnaces, and in so many comparable situations. But when injuries and deaths are steadily caused by products that don't make headlines, perhaps because the problem has not yet reached critical proportions, our action must be no less effective. In fact, the CPSC works to head off suffering before any deaths or injuries have occurred, or before any more can occur. We are not so shortsighted as to wait, nor did Congress want us to wait, for a body count to accumulate.

With severe budget limitations, however, the Commission will find it increasingly difficult to stay this course. Since we can't turn our backs on the hazards that demand immediate attention, we find ourselves increasingly forced to stop or slow work on projects designed to prevent potential risks from ever seeing the light of day.

Congress created the CPSC to stay on top of injury trends, spot needless risks before many--or any--consumers are hurt, and do the underlying research and investigative work that this task requires. The blunt truth is that we can't faithfully carry out this mandate with a budget of $23.7 million and 568 FTE's. To counter the risks discussed in this letter--in the thoroughgoing and professional way the American public rightfully expects--we need considerably more resources. I have tried to document what the looming shortfall means in explicit terms with respect to the day-to-day lives of real people, most of whom assume we're as vigilant as ever. The fact is, we're not. We can't possibly be when staff and funding have been so conspicuously axed.

I trust these facts will assist you in carrying out your exceedingly difficult responsibility. As always, I would be pleased to furnish any further details or clarification of the Commission's resource plight.

Sincerely,

Stuart M. Statler
Commissioner

cc: Honorable Patrick J. Leahy
Ranking Minority Member

STATEMENT SUMMARIZED

Mr. STATLER. I would like to summarize my official statement at this time.

I take sharp exception to the budget as submitted to this committee. I take exception because, although our huge Federal budget deficit underlies the administration's desire to cut Federal spending and is understandable and in many ways commendable, what is not understandable is its determination that this agency, CPSC, shoulder a disproportionate share of this budget cut burden.

EROSION OF BUDGET AND PERSONNEL

Our budget and staffing have been steadily eroding in recent years. Taking inflation into account, the OMB imposed budget for fiscal year 1986 represents a decrease in real dollars compared to our startup in 1974 of a whopping 53 percent; a 53-percent decrease in 12 years for this agency.

No other budget of a Federal health and safety regulatory agency in this Government comes anywhere close to that precipitous decline. In fact, EPA's budget had jumped 87 percent in that period, and during the same period, OSHA's budget has risen 32 percent.

When OMB expects us to spend in terms of 1974 dollars the equivalent of $14,690,000 next year to attempt to reduce the hazards that cause innumerable fires, electrocutions, asphyxiations, poisonings, cancers, and other product-related calamities that beset our citizens in their everyday lives, I think that is wrong. The 15,000 products under our jurisdiction kill 3 Americans every hour of every day, and 3,700 other Americans are seriously injured hourly. Yet CPSC's budget and staff sink lower and lower each year. Adjusting for inflation, compared to our current fiscal year 1985 funding level, the fiscal year 1986 budget is down 10 percent. Compared to our funding level just 5 years ago at the start of this administration, our fiscal year 1986 budget is down a startling 36 percent.

The past 5 years also evidence the evisceration of CPSC's staff. The OMB-imposed level of 568 FTE's for fiscal year 1986 also represents a 36-percent swipe since 1981 when 889 FTE's were authorized. This means a 36-percent cut in staffing and funding since 1981. The bottom line is that both our staff and our funding are down more than one-third.

ALL-TERRAIN VEHICLES

My statement focuses on a particular glaring example of why we are behind, and that is the ATV situation—the all-terrain vehicles—that the chairman mentioned. Although I won't go into detail, I think that you should understand that now having identified ATV's as perhaps the most urgent blip to ever appear on our emerging hazards screen, we are posed to swing into action. But to do that means that next week we must first go through the excruciating exercise to decide what other worthy projects need to be dropped from our fiscal year 1986 operating plan in order to free up those resources for the pressing all-terrain vehicles work.

Surely, Congress envisioned something else 12 years ago. I worked on the legislation myself.

The Commission is the only agency in the Federal Government with a responsibility under law to do something about this ever-worsening ATV problem and so many others. What we decide will determine literally how many thousands of youngsters and others in your State and all the other 49 States will be saved from serious injury, paralysis, and death over the months immediately ahead and long into the future and how many will not be saved.

The problem goes way beyond ATV's. Dozens of our current projects are delayed or can't even get off the ground, thus needlessly risking the lives of unsuspecting American families. Many other deserving projects were scrapped before even making it into our original austere budget submission for 1986, which simply represented our 1985 figure, plus inflation.

This is happening only because the CPSC has been underfunded and understaffed since 1981, when we had nearly 900 FTE's and a budget of approximately $42 million. People at OMB who cut our budget year after year seem ideologically opposed to doing anything in this area, other than redesigning the behavior of consumers, which is next to impossible, rather than where appropriate, redesigning hazards out of the products.

WORTHY PROJECTS ELIMINATED

The worthy projects on our cutting room floor range from child drownings and other tragedies causing physical trauma to kids in swimming pools to cutting back work on airborne microbes that can infest the heating and cooling systems of our homes; from correcting the explosion risk from damaged flexibile connectors in gas appliances to determining why some circuit breakers fail to trip and prevent home fires and electrocutions; from minimizing disfiguring burns caused by electric deep fat fryers to the averting of the tragic crunching of youngsters by unyielding garage doors.

In conclusion, these projects aren't found in our budget, but the risks associated with them abound in our homes, causing death, serious injury and illness, and wholesale property destruction.

The projects aren't drawn from some pie in the sky wish list. They are basic to our operation because the risks are ever present. We wish they weren't in such abundance, but they are. At the rate we're going, CPSC can be nickled and dimed 5 percent here, 10 percent there for a few more years before we are so emasculated that we won't be able to do any meaningful safety work. Only this committee is in a position to prevent that. Only this committee can reverse the erosion of fundamental protection against risks found around the home that the American public rightfully expects and deserves.

Mr. Chairman, now that you have taken over, the issue that I earlier touched upon in my statement and our Chairman's statement concerned the increasing use, injuries, and deaths associated with all-terrain vehicles. Just yesterday, I received two phone calls for me in that State from Arizona and from the CBS affiliate out of Phoenix.

Senator DOMENICI [presiding]. I am from New Mexico. [Laughter.]

Mr. STATLER. I am sorry.

Senator DOMENICI. We have two Italians; you get us mixed up. One is DeConcini. I am Domenici.

Mr. STATLER. Forgive my faux pas. The problem is as great in your State as in neighboring Arizona. I am sure you will be hearing more about it, unfortunately, as we will.

Senator DOMENICI. Did you have a statement, ma'am?

Ms. DAWSON. Just briefly.

Senator DOMENICI. Surely.

STATEMENT OF CAROL G. DAWSON

Ms. DAWSON. Thank you, Mr. Chairman. I am the newest member of the Consumer Product Safety Commission. I am pleased to appear here today to support the 1986 budget request of $33.7 million. At a time when serious problems of deficits plague decisions about funding, I believe it is more important than ever before for this Commission to carry out its mandate at the least possible cost to the taxpayer. In spite of the cuts sustained to the agency over the past 3 years, it is still functioning in an effective and dedicated manner in carrying out its mission. Taking into account the mission of the agency and the need for cost containment, I believe the Commission is submitting a budget request which is both realistic and manageable.

PREPARED STATEMENT

Mr. Chairman, there is more to my statement. I request that the balance of my remarks be included in the record and again indicate that I do support our current budget request.

Senator DOMENICI. Without objection, it will be submitted.

[The statement follows:]

STATEMENT OF COMMISSIONER CAROL G. DAWSON

Mr. Chairman and Members of the Subcommittee, as the newest member of the Consumer Product Safety Commission, I am pleased to appear today to indicate my support of the agency's Fiscal Year 1986 Budget Request of $33,700,000.

At a time when serious problems of federal deficits plague decisions about funding for all government agencies, it is more important than ever for this Commission to carry out its mandate at the least possible cost to the taxpayer. Despite the cuts sustained by the agency over the last three years, it is still functioning in an efficient and dedicated manner in carrying out its mission.

Taking into account both the mission of the agency and the need for cost containment, I believe that the Commission is submitting a budget request which is realistic and manageable. Significantly, in Fiscal Year 1986 the Commission recognized the need to limit the number of priority projects. By reducing the number of projects from nine in FY 1985 to five in FY 1986, the Commission can focus on specific product areas, while retaining maximum flexibility to carry out other important projects.

One of the areas where I believe the Commission can achieve better cost-effectiveness is through improvements in its state and local program. Section 29(a) of the Consumer Product Safety Act embodies Congress' desire to see such cooperation take place. In previous years, the Commission has seen the value of joining forces with state and local agencies to stretch Commission resources. But, the Commission's failure to establish a continuing, active program of state and local cooperation was a major shortcoming.

During considerations on 1986 priority setting, and subsequently, during the 1986 budget deliberations, I proposed establishment of just such a continuing, fully-funded program for FY 1986. The other Commissioners concurred, and I believe this should implement Congressional direction in Section 29(a) of the CPSA, while enhancing the ability of the agency to protect the public.

The Commission wishes to allocate $250,000 to this program in FY 1986--a significant increase over the zero-level funding for FY 1983. This will enable regional offices to reestablish networks and sources of information within their geographic areas in an orderly manner.

As part of this renewed emphasis on state and local cooperation, an import surveillance program is scheduled to begin in FY 1986. Where possible, the Commission will work with state and local officials in performing port-of-entry surveillance of selected products, such as toys and flammable fabrics, in order to identify violative products before they enter domestic commerce.

Another area of CPSC operations in which I have a special interest is the 1985 Management Review. Such a review will assist the Commission in finding ways to carry out its mission in the most cost-effective manner, without skimping on hazard programs. Examination of the "matrix" system of management with a view towards eliminating overlap in supervision of programs, a hard look at methods of consolidating services, and a study of the field organization are all part of the scope of the review.

I believe that the Commission staff can continue to function effectively with a 1986 funding level of $33,700,000 and 568 FTEs. With intelligent planning and programming, and the exercise of fiscal restraint, this agency will continue to fulfill it statutory responsibilities.

FIVE PRIORITY AREAS

Senator DOMENICI. Thank you very much.

Let me just ask one question of you, sir.

In 1986, you have identified five priority items or areas: electrocution hazards, gas heating systems, portable electric heaters, riding mowers, and toxicity, which was formerly called toxicity of combustion products. Would you briefly indicate for each of these five areas the amount of money that is being allocated to each area, the change in the funding level in each priority area from OMB's budget request level, and the implication of this change in terms of the kind of activities that will be conducted?

Mr. Chairman, would you answer that for us, please?

Mr. SCANLON. I would be happy to, Senator. The dollar amount for fire toxicity for fiscal year 1986 is $800,000. The dollar amount requested for electrocution hazards is $204,300; the amount for riding mowers requested is $476,800; the amount for gas heating is $442,800; and the amount requested for portable electric heaters is $289,700.

There is no change in the amount of moneys from the $37.5 million figures and this new reduced $33 million budget request.

Senator DOMENICI. Will there be any change in terms of the activities that you will conduct in 1986 over 1985?

Mr. SCANLON. No, not in the priority projects.

SUBMITTED QUESTIONS

Senator DOMENICI. We have a number of questions that we are going to submit for you to answer in writing. If you would do that as quickly as possible, the subcommittee would appreciate it.

Mr. SCANLON. We will be happy to.

Senator DOMENICI. Thank you very much.

Mr. SCANLON. Thank you, Senator.

Senator DOMENICI. Could we please have order, please? Thank you very much.

[The following questions were not asked at the hearing but were submitted for response for the record:]

QUESTIONS SUBMITTED BY SENATOR GARN

MOST SIGNIFICANT ACCOMPLISHMENTS

Question: Mr. Chairman, in response to a question last year to describe the one accomplishment of the Commission that she was most proud, Chairman Steorts indicated it was the partnership developed between the Commission, private industry and the consumer.

How would you respond to the question of what Commission accomplishment would you identify as being the most significant?

Answer: I agree that a cooperative partnership between the Commission, industry and consumers is critically important in promoting greater consumer safety. Additionally, this new cooperative spirit is being developed with State and local government consumer protection agencies. Together, we can work to expand our resources, alert consumers of hazards and recalls, and strengthen overall product safety at all levels of government.

FY 1985 PRIORITY PROJECTS

Question: Four FY 1985 priority projects: Chlorocarbons, Indoor Air Quality, Nursery Equipment and Safety for Older Consumers are not Commission priorities for FY 1986. Would you please list the major accomplishments during FY 1985 for each of these priority projects? What is the reason for dropping chlorocarbons from the priority list in FY 1986?

Answer:

Chlorocarbons. During FY 1985 the accomplishments in the Priority Project on Chlorocarbons will include:

- o completion of the review of the recent National Toxicology Program inhalation on methylene chloride;
- o initiation, with the Environmental Protection Agency, of a jointly funded survey to determine how consumer's use products which contain chlorocarbons. This information is important in determining the extent of consumer exposure;
- o completion of controlled laboratory studies which will assist in determining the extent of consumer exposure to methylene chloride from use of consumer products such as paint strippers and aerosol spray paints. These studies are being conducted at Lawrence Berkeley Laboratory using a protocol that was peer reviewed by outside scientists, including industry and consumer groups;
- o development of preliminary exposure and risk estimations for methylene chloride from consumer products.

Chlorocarbons require priority attention during FY 1985 as most of necessary scientific assessment and research to determine the extent of consumer exposure and risk will be undertaken in FY

1985. In FY 1986 the staff will be continuing to work with the industry and public to address whatever questions may remain about the safety of methylene chloride and other chlorocarbons, but the major portions of this investigation will be completed.

Indoor Air Quality

During FY 1985 the accomplishments in the area of Indoor Air Quality will include:

- complete an analysis of the potential for adverse health effects from pollutant emmissions from wood stoves;
- evaluate available data on gas stove emissions and the potential for adverse health effects;
- work with industry and consumer representatives on the development of a voluntary standard to limit emissions of nitrogen dioxide from kerosene heaters. The Commission staff is assisting Underwriters Laboratories in the development of a method of testing NO_2 emissions from kerosene heaters that can be used in certification testing;
- evaluate and encourage new technology in burner design and catalysts which may reduce pollutant emissions from kerosene heaters;
- continue working with the Gas Research Institute, the Gas Appliance Manufacturers Association and other interested gas industry representatives to complete an analysis of the potential for adverse health effects from the indoor pollutants emitted by gas space heaters;
- complete a monitoring study in homes in the southern United States which use unvented gas space heaters. This study will better enable us to evaluate the potential for adverse health effects from the use of these heaters, and hopefully lead to the development of a voluntary standard to limit indoor emissions from these appliances;
- complete final report on the CPSC sponsored indoor air monitoring study conducted by Oak Ridge National Laboratory (ORNL). This study found from 20 to 150 volatile organic compounds (VOCs) indoors, and fewer than 10 VOCs outdoors. The levels of VOCs indoors were generally higher than outdoor levels; many VOCs appear to come from the use of various consumer products including paints, varnishes, aerosols, cleaners, polishes, plastics, furnishings and pressed wood products. The presence of complex mixtures of volatile organic chemicals has been associated with the symtomatology generally known as sick building syndrome;
- coordinate with ORNL and other Agencies in conducting additional monitoring studies on volatile organics in residential air.

Indoor Air Quality has been a Commission priority since FY 1981 (as the project Tighter Thermal Envelopes). During that time much has been accomplished to reduce the contribution of consumer products to indoor air pollution:

- formalydehyde emissions from pressed wood products have been reduced and the use of urea-formaldehyde foam insulation largely discontinued;
- heating appliances like kerosene heaters and unvented gas space heaters and wood stoves have developed improved designs which reduce pollutant emissions;
- manufacturers are developing devices which can better monitor the indoor air for the presence of pollutants and remove offensive or hazardous pollutants from indoor air.

CPSC is, however, only one of several Agencies that have responsibility for addressing indoor air pollution. CPSC, through the Federal Interagency Committee on Indoor Air Quality (CIAQ), which we co-chair with DOE, DHHS and EPA, has been working to coordinate the needed research, assure maximum benefits from the limited available resources, and obtain information on the contribution of consumer products to indoor air pollution.

CPSC and DOE staff assisted EPA staff in the preparation of a Comprehensive Strategy on Indoor Air Quality which EPA will be submitting to Congress on behalf of the 15 Agencies who participate in the CIAQ. The CPSC staff also assisted in preparing comprehensive reports on current Federal research on indoor air quality issues. These reports will be distributed to the public and private sector to increase communication and assure maximum utilization of the results of government sponsored research.

Since Congress had provided the EPA with an additional $2 million for indoor air quality research during FY 1985 and is considering a similar additional line item appropriation for FY 1986, the Commission did not believe that priority attention was necessary beyond FY 1985.

Nursery Equipment Information Program

In FY 1985, the accomplishments of the Nursery Equipment Information Program are:

- produced and distributed a comprehensive checklist on nursery products (e.g., cribs, strollers, walkers, high chairs, etc.);
- distributed, in collaboration with Gerber, Inc., a major manufacturer of children's products, a CPSC brochure on nursery equipment safety to more than two million parents of infants;

- provided funds to state and local organizations to conduct "expectant parent seminars" in hospitals, clinics, and health centers in many communities.

This program is being evaluated to measure increases in knowledge and self reported behavior change among consumers who receive CPSC materials.

In FY 1986, CPSC will not devote "priority" attention to this campaign because the materials will have been developed and evaluated and the series of "expectant parent seminars" will have been conducted. As a part of CPSC's ongoing/seasonal information effort, we will continue to reprint and distribute nursery equipment materials for use by health centers and individual consumers who request them. CPSC will continue this "maintenance level" effort in future years but will not list this program as a "priority."

Safety for Older Consumers

The FY 1985 accomplishments of the Safety for Older Consumers program will be:

- Nationwide distribution of the Home Safety Checklist for Older Consumers to all State Units on Aging, all 660 Area Agencies on Aging, and all other national organizations serving older consumers (e.g., American Association of Retired Persons, the National Council on the Aging, the National Council of Senior Citizens, et. al.);
- To work with The Department of Health and Human Services (HHS) to reprint one million copies of the checklist for distribution through the network of Area Agencies on Aging;
- To fund purchase orders to 32 State and local organizations to conduct seminars for older people and to distribute the Checklist;
- To encourage State and local agencies and private sector organizations serving older people, to use the Checklist in their ongoing programs;
- To translate the Checklist into Spanish and distribute throughout the CPSC Regional Offices;
- To hold a national news conference to announce a national conference on Safety for Older Consumers (now planned for September, 1985,) to explore avenues of voluntary efforts to address hazards encountered by older people. CPSC will co-sponsor the conference with the American Society for Testing and Materials, the major voluntary standards organization in the U. S.

In FY 1986, CPSC will not devote "priority" attention to this campaign because the Checklist will have been developed and widely distributed, and the national conference held. CPSC will continue to distribute the Checklist in response to requests, and CPSC will follow-up on recommendations from the conference through our voluntary standards effort.

STATE AND LOCAL PROGRAMS

Question: In response to a question at last year's hearing, CPSC indicated it planned to allocate $100,000 and two FTEs in FY 1984, and the same resources in FY 1985 for State and local programs. Since that point, we understand these numbers have changed.

What was spent in FY 1984?

Answer: In FY 1984, the following resources were spent on the State/local programs:

$100,000

4 FTEs

Question: What do you estimate for FY 1985 and for FY 1986?

In FY 1985, we estimate $100,000 and 4 FTEs. In FY 1986, we estimate $250,000 and 4.5 FTEs.

BILL LANGUAGE

Question: This year it appears that you are once again requesting that three provisions contained in the FY 1985 bill be deleted in FY 1986. These provisions are the references to:

- hire of passenger vehicles;
- GS-18 pay cap on consultant services;
- restricting funds to the acquisition and conversion of existing laboratories.

Could you please explain the reasons for each of these proposed changes?

Answer: During preparation of the FY 1986 Budget, the Office of Management and Budget instructed CPSC to drop all three of these provisions from the bill language. OMB felt that these items were redundant, could be handled under general provisions and were not necessary in CPSC's specific appropriation language.

TRAVEL AND TRANSPORTATION

Question: Travel and transportation has been generally increasing each year. You expect your FY 1986 travel of persons to be up 9% and your other transportation costs to be up 43% over the FY 1984 actuals in these two categories.

Would you please explain these increases?

Answer: The 9% increase in travel of persons is due to anticipated higher travel costs, for example an increase in travel associated with training and attendance at voluntary standard meetings and trade shows, etc.

The 43% increase in other transportation cost is due to increased cost in postage rates for shipment of samples such as kerosene heaters, toys and cribs, and costs which may occur if six additional resident posts are opened.

PERSONNEL APPOINTMENTS

Question: Your budget justification indicates that $15,000 in FY 1986 will be available under consulting services for personnel appointments. Apparently these are experts providing technical services.

Would you please indicate why these are called personnel appointments?

Answer: The expert consultants hired by the Commission support the Compliance and Enforcement program. They are classified as personnel appointments in accordance with the definitions found in OMB Circular No. A-120, Guidelines for the Use of Consulting Services.

Question: Who selects these individuals?

Answer: The individuals are selected by the Directorate for Compliance and Administrative Litigation after consultation with the necessary technical staff.

Question: Have any of these experts the Agency anticipates using, performed similar services in the past?

If so, for how many years?

Answer: Until recently the Commission infrequently used consultants for Compliance and Enforcement. In the past two years, because of increased technically complex litigation, this practice has increased. Three individuals currently being used have been used on a recurring basis over the past two years in the Honeywell litigation matter.

Question: Please list the specific areas of expertise for which individuals are being considered for FY 1986?

Answer: The specific areas of expertise for which individuals are being considered for FY 1986 cannot be identified at this time. The expertise needed in FY 1986 will be based on the types of investigations and/or litigation being conducted at that time.

However, general disciplines such as human factors, child development, and marketing are types of expertise most likely to be required.

FIELD PERSONNEL

Question: Last year, you were asked what was the level of intercoder reliability among the CPSC Field personnel that code accident data. The CPSC response indicated that "no quantitative measures of inter-investigator reliability are available," however, based on training - a F.I. Manual - and supervisory review there is "consistency, reliability, and validity among investigators."

It would seem if there are common accident coding forms and training manuals, it would be possible to send out several common accident cases to all field investigators and have each complete the accident forms.

Has CPSC ever done this?

If so, what were the results?

If not, when can the Subcommittee expect such an effort?

Answer: CPSC has never conducted a study of intercode reliability among its field investigators. The coding of data on all investigations is routinely checked and corrected at the supervisory investigator level, and errors occur very rarely. While CPSC will conduct a study, if requested by the Subcommittee, it expects that the error rate would be minimal to zero.

The coding of investigation reports performed by investigators is simple and involves straight forward coding instructions. There are 11 categories of data which must be coded by an investigator on a report. These categories are:

a. Location of incident (home, school, etc.)

b. State in which the incident occurred.

c. Product code(s) from National Electronic Injury Surveilliance System (NEISS) coding manual.

d. Sex of injured person.

e. Medical disposition (no treatment sought, admitted to hospital , etc.).

f. Injury diagnosis (fracture, etc.)

g. Body part injured.

h. Type of respondent providing report data (victim, eyewitness, etc.).

i. Type of investigation (on-site, telephone, etc.).

j. Type of attachments to report (photographs, sample of product, etc.).

k. Case source (complaint, NEISS, etc.).

With the exception of data items d and i (victim's sex and investigation type), the investigator must provide a brief description next to the coded information. The numerical code is checked against the description and the information contained in the report narrative by a reviewer in the Directorate for Epidemiology prior to entry into the computer. Few errors are found in the 3,000 reports reviewed annually.

The coded information is primarily used for cross-referencing and indexing purposes. Analysts in the Directorate for Epidemiology use the report narrative to identify and analyze the factors that caused or contributed to an accident or incident.

Variability between investigators can become critical in interviewing respondents, conducting an examination of a product and writing the narrative portions of the report. To assure consistency in these areas, investigators are given technical guidance to compete for investigations of specific hazard patterns and products, training in conducting all phases of investigations. In addition, analysts routinely provide feedback on the quality of investigations they review. The supervisory investigator is responsible for assuring that the investigators follow good investigatory procedures when conducting and reporting on an investigation.

Question: The current Chairman's response to last year's question on distribution of CPSC personnel indicated a desire for an equal number in the field as in Headquarters. Such a distribution would make it critically important that the data gathered be as quantitative as possible and that techniques for insuring that both intercoder reliability and validity be maximized.

Would you please provide, for the record, the outline for a multi-year plan with milestones to insure that testing is introduced to check on field investigator training at a national level?

Answer: The Commission as part of its FY 1985 Operating Plan decisions directed that $30,000 be spent for a national and regional level product safety investigation training program and also directed the Field to set-aside $35,000 of its travel allowance to fund travel associated with the training program. The following outline of the multi-year product safety investigator training plan also provides appropriate knowledge and skill professional/technical development for the recently converted public affairs specialists. A revised Field investigator training manual is scheduled for completion by no later than second quarter FY 1986.

Field Investigator Training Program

FY 1985 Third Quarter

a) A training needs assessment is proposed for late in 3rd Quarter at the same time;

b) New investigators will receive in-service basic training on investigation theory (interviewing, affidavits, evidence collection, rules of evidence, coding, photography and practice), inspections, sample collections, recall effectiveness checks and related topics.

Fourth Quarter - New investigators will attend a 2-3 day training course in Washington, D. C., conducted by Headquarters staff on investigational and inspectional techniques. A pre and post training questionnaire will be administered to measure knowledge levels.

FY 1986 First Quarter

a) Development of a Field Investigator Training Manual;

b) In addition Commission authorization of expenditures will be requested to fund, as an ongoing activity, a project for analysts from the Directorate of Epidemiology to visit each of the 5 Regions for 1-2 days, to train staff on special hazard analysis studies. Supervisory investigators will travel to Headquarters to participate in 'training the trainers' training programs in order to develop and implement regional level performance based training programs utilizing State/local health/safety institutions and public service utilities, expert technical personnel, and public/private academic and scientific organizations.

c) Pre and post tests will be administered. Cost is estimated at $12,000 - $15,000 for Headquarters and field travel (resident post staff must travel to Regional Offices to receive training).

FY 1987 Quarterly - Investigators/supervisors will continue to receive general guidance via a monthly memorandum; analysts will continue to critique investigations and provide investigators and supervisors with comments. Technical guidance will be issued or, if necessary, revised for products or hazard patterns.

OTHER SERVICES

Question: Other than for personnel compensation, the largest expenditure by object classification is Object Class 25.0, Other Services.

What are the major items that make up this $5,326,000 request?

Would you please make up a table for the record showing a detailed breakdown of Object Class 25.0 for FY 1984 actual and estimated FY 1985 and FY 1986?

Answer: The following table provides a breakdown of the major items which make up the $5,326,000 planned expenditures in Object Class 25 for FY 1986, as well as a similar breakdown for FY 1984 and FY 1985.

	Object Class 25 ($000)		
	1984	1985	1986
Program Contracts 1/	3,923	3,214	3,245
Operating Cost 2/	226	179	175
Common Cost:			
Copying Services	169	169	169
Security/Guards	217	219	209
Training	35	66	66
Labor Services/Renovation	85	100	116
Other Common Costs 3/	183	209	224
Computer Cost 4/	1,081	1,100	1,122
TOTAL	5,919	5,256	5,326

1/ Includes Hazard Program contracts such as fire toxicity, riding mowers, indoor air quality, etc., and Support Program contracts such as data collection, lab support, economic support, etc.

2/ Operating cost includes repairs and maintenance contracts for office, lab and science equipment, media acquisitions and productions, conference registration fees, etc.

3/ Other common cost includes word processing and copying equipment maintenance, library research contract, payroll services, and health unit contract.

4/ This includes Parklawn Computer Center charges and a data entry contract.

RECALLS

Question: How does the number of recalls conducted by the Commission in FY 1985 compare with prior years? Would you please update, for the record, the list provided on page 182 of your FY 1985 Senate Appropriations Hearing?

Answer: As of March 1, 1985, we have initiated 36 substantial product hazard recall actions and 44 Section 15 regulated product recall actions. The rate for regulated product recalls is up when compared to the last three years. For the substantial product hazard recall actions, the rate is lower. However, because of the increase in the number of substantial product hazard reports received in FY 1985, the number of these recall actions initiated by the end of the year will probably be about the same or higher than the last three years.

Substantial Product Hazard

FY	Number of Recall Actions Initiated	Number of Products Involved	Number of Products Corrected to Date
1979	198	53,555,927	4,443,950
1980	132	23,310,834	3,629,726
1981	99	2,475,455	635,375
1982	91	2,570,117	460,913
1983	113	23,253,383	1,050,364
1984	106	7,094,427	1,710,609

Regulated Product Recalls

FY	Number of Recall Actions Initiated	Number of Products Involved	Number of Products Corrected to Date
1979	347	4,478,863	297,728
1980	456	11,793,910	5,067,560
1981	251	3,811,746	1,152,720
1982	72	1,073,455	610,234
1983	66	31,387,967	25,904,985
1984	66	795,300	134,523

COURT SUITS

Question: Would you please provide, for the record, the number of court suits CPSC has initiated in each year from FY 1980 through FY 1984?

Answer: COMPLIANCE - Administrative Litigation initiated from FY 1980 through FY 1984.

- FY 1985 No administrative litigation initiated as of March 31, 1985.
- FY 1984 In re: Memline Corp. et al., CPSC Docket No. 84-2. The CPSC filed an administrative complaint, naming six manufacturers of children's expandable enclosures, that seeks corrective action to address the risk of strangulation associated with these products.

  In re: Honeywell, Inc., CPSC Docket No. 84-1. The CPSC filed an administrative complaint seeking corrective action to address the risk of injury and death from fires and explosions associated with the V5130 LP Gas control valves used in certain water heaters.
- FY 1983 In re: Bilt-Rite, et al. CPSC Docket No. 83-4.

  In re: Janex Corporation, CPSC Docket No. 83-3.

  In re: Honeywell, Inc., (V8280) CPSC Docket No. 83-2.

  In re: Sun and Sand Imports, Ltd. and Guido Muller. CPSC Docket No. 83-1.
- FY 1982 In re: Edgewood Chenille Co., CPSC Docket No. 82-4.

  In re: Robertshaw Controls Company., CPSC Docket No. 82-3.

  In re: Ford Manufacturing Co., CPSC Docket No. 82-2.

  In re: Roper Corp. and Sears, Roebuck and Company., CPSC Docket No. 82-1.
- FY 1981 In re: Investigation of Federal Pacific Electric and Reliance Elec., CPSC Docket No. 81-7.
  In re: Western Publishing Co., Inc., CPSC Docket No. 81-6.

In re: Hollywood Needlecraft, Inc., CPSC Docket No. 81-5.

In re: S. Schwab Co., Inc., CPSC Docket No. 81-4.

In re: John R. Lyman Co., Inc., CPSC Docket No. 81-3.

In re: Crown-Tex Corp., CPSC Docket No. 81-2.

In re: A&B Wiper Supply, Inc., CPSC Docket No. 81-1.

o FY 1980 In re: Lorenzo Pucillo & Son, CPSC Docket No. 80-10.

In re: Don's Carpet Inc., et al., CPSC Docket No. 80-9.

In re: State Fair of Texas Inc., CPSC Docket No. 80-8.

In re: Marriott Corp., CPSC Docket No. 80-7.

In re: Century Products., CPSC Docket No. 80-6.

In re: Athlone Industries, Inc., CPSC Docket No. 80-5.

In re: Advance Machine Co., CPSC Docket No. 80-4.

In re: MTD Products d/b/a/ Columbia Bicycle, CPSC Docket No. 80-3.

In re: Imperial Carpet Mills, Inc., CPSC Docket No. 80-2.

In re: Swiss Sky Ride, State Fair of Texas, CPSC Docket No. 80-1.

Federal Court Litigation Initiated

Question: Would you also provide, for the record, the name of each suit initiated in FY 1984 and FY 1985 to date, together with a brief one sentence description of each?

o FY 1984

1. U.S. v. Craig L. Macrow d/b/a/ Empire Supply House

   Suit to enjoin shipment in interstate commerce of banned fireworks devices. (W.D.N.Y.)

2. U.S. v. Capitol Fireworks Company

   Suit to enjoin shipment in interstate commerce of banned fireworks devices. (C.D. Ill.)

3. U.S. v. Honeywell, Inc.

   Suit to assess civil penalty for alleged violation of Section 15(b) reporting requirements. (D. Minn.)

4. U.S. v. Articles of Banned Hazardous Substances

   Seizure of baby rattles. (E.D.N.Y.)

FY 1985

1. U.S. v. Inventive Packaging Corporation

   Suit to enjoin manufacture of child-resistant vials.

   (D.Colorado)

2. U.S. v. Karen L. Mages

   Suit to enjoin shipment in interstate commerce of banned fireworks devices. (W.D.Missouri)

SUMMARY OF RESOURCES

Question: Would you please provide, for the record, a table showing a distribution of the requested FY 1986 funding by object classification for the following resource categories:

- o Commission Policy Development and Direction
- o Product Safety and Enforcement (Subtotal)
  - o Executive Direction
  - o Hazard Programs
  - o Ongoing Activities

Answer:

	Salaries ($000)	Operating/ Common Cost ($000)	Contracts ($000)	Total ($000)
Commission Policy Development & Direction	2,838	823	11	3,672
Product Safety and Enforcement (Subtotal)	17,282	4,992	4,123	26,397
Executive Direction	(832)	(219)	(42)	(1,093)
Hazard Programs	(6,063)	(1,738)	(1,373)	(9,174)
Ongoing Activities	(10,387)	(3,035)	(2,708)	(16,130)
Administration and General Support	2,430	798	403	3,631

PROGRAM CHANGES

Question: Last year, you provided the Subcommittee with a detailed list of program changes between FY 1983 to FY 1985.

Would you please provide, for the record, a similar listing of programs showing the anticipated changes between FY 1985 and FY 1986?

Answer:

Explanation of Changes
FY 1985 to FY 1986

Commission Policy Development Program

FY 1985 - FY 1986 (-$349,000)

- o The personnel levels in the Office of the Secretary and the Office of the General Counsel were reduced by a total of 3 full-time equivalent's (FTEs). The dollar decrease is a result of the salary savings from these positions; a

5% salary reduction; and an overall 10% administrative cost reduction.

Executive Direction Program

FY 1985 - FY 1986 (-$98,000)

- The decrease in funds is a result of a 5% salary reduction and a 10% administrative cost reduction.

Emerging Hazards Program

FY 1985 - FY 1986 (+$49,000)

- The increase in funds is due to addition of resources for the product safety assessment/Section 15 project.

Fire and Thermal Burn Program

FY 1985 - FY 1986 (-$382,000)

- The reduction in resources is due to decreases in positions and funds for the wood/coal heating equipment project, metal chimney project, and bedding fires project.

Electrical Hazards Program

FY 1985 - FY 1986 (-$56,000)

- Projects in all CPSC programs compete for resources. The Commission made budget decisions which resulted in a slightly smaller electrical program. The change is not significant.

Chemical Hazards Program

FY 1986 - FY 1986 (-$756,000)

- The reduction in resources is due to decreases in the positions and funds for the IAQ project, chlorocarbon project, sensitive population project and strong sensitizer project.

Children's and Recreational Products Program

(No contract dollars had been allocated.)

- The decrease in resources is due to the elimination of the crib structural integrity project and the squeeze toys project.

Power Equipment Program

FY 1985 - FY 1986 (-$95,000)

- The decrease in funds is due to the reduction in funds for the chain saw project; the 5% salary reduction; and an overall 10% administrative cut.

Household Structural Products Program

FY 1985 - FY 1986 (-$126,000)

- The reduction is due to a decrease in resources for the pressed wood project.

Hazard Identification and Analysis Program

FY 1985 - FY 1986 (-$212,000)

- The decrease in funds is due to the reduction in resources for statistical support; a 5% salary reduction and a 10% administrative cost reduction.

Engineering and Sciences Program

FY 1985-FY 1986 (+$171,000)

- The resources in this program are for general support activities in the Engineering Sciences and Health Sciences Directorates and laboratories. These resources have been increased in relation to the above Directorate's project requirements.

Information and Education Program

FY 1985 - FY 1986 (-$319,000)

- The decrease is due to the fact that there are no Information and Education campaigns planned for FY 1986 as well as a reduction of 2 positions in the Office of Public Affairs.

Compliance and Enforcement Program

FY 1985 - FY 1986 (-$63,000)

- The reduction in funds is due to decrease in resources for the household chemical enforcement project.

Field Activities Program

FY 1985 - FY 1986 (+$103,000)

- The increase in funds is due to an increase in State and local contracts which we partially offset by a reduction in operating expenses.

Administration and General Support Program

FY 1985 - FY 1986 (+$3,000)

- There are no significant changes in this program.

EXPLANATION OF FY 1986 BUDGET CHANGES

Question: Would you please provide, for the record, a descriptive comparison for each Agency program between the October 1984 - FY 1986 Budget and the January 1985 - FY 1986 Budget.

Answer:

EXPLANATION OF CHANGES
October to January Budgets

Commission Policy Development Program (-$475,000)

- Decrease due to salary savings of 3 FTEs; 5% salary reduction; and a 10% reduction in administrative/operating cost.

Executive Direction Program (-$199,000)

- Reduction due to salary savings of 1 FTE and a decrease in contract support for management evaluation analysis.

Emerging Hazards Program (-$136,000)

- Decrease due to 5% salary reduction and 10% administrative/operating cost reduction.

Fire and Thermal Burn Program (-$302,000)

- Decrease due to salary savings of 2 FTEs and the reduction of contracts for the fire investigation project.

Electrical Hazards Program (-$121,000).

- Reduction due to 5% salary reduction and elimination of contract funds for the fire investigation project.

Chemical Hazards Program (-$274,000)

- Decrease due to salary savings of 2 FTEs and a reduction in contract support for the IAQ project.

Children's and Recreational Products Program (-$158,000)

- Decrease due to salary savings of 2 FTEs; 5% salary reduction; and a 10% reduction in administrative/operating cost.

Power Equipment Program (-$154,000)

- Reduction due to the elimination of contract dollars for evaluation of mower standard project; a 5% salary reduction; and a 10% decrease in administrative/operating cost.

Household Structural Products Program (-$124,000)

- Decrease due to salary savings of 1 FTE; a 5% salary reduction; and a 10% cut in administrative/operating cost.

Hazard Identification and Analysis Program (-$237,000)

- Decrease due to salary savings of 1 FTE and a reduction of contracts for economic special studies/support projects.

Engineering and Sciences Program (-$135,000)

- Decrease due to a 5% salary reduction and decrease in contracts for engineering lab support and lab equipment.

Information and Education Program (-$593,000)

- Reduction due to salary savings of 3 FTEs and elimination of contracts for the child safety project.

Compliance and Enforcement Program (-$277,000)

- Decrease due to salary savings of 1 FTE; 5% salary reduction and reduction of contract support for Section 15.

Field Activities Program (-$57,000)

- Decrease due to cut in operating expenses.

Administration (-$408,000)

- Decrease due to salary savings of 2 FTEs; 5% salary reduction and a 10% administrative/operating cost reduction.

CPSC LABORATORY

Question: The CPSC Laboratory in Gaithersburg, Maryland, conducts a diversity of testing programs including products such as: chain saws, stoves and heaters, children's toys, flammability testing of furniture and future testing of riding mowers and all terrain vehicles.

The test equipment being used has the appearance of not having been updated since the lab was set up over a decade ago.

What would it cost to replace the most obsolete test equipment with the latest technology equipment?

What would be the pay off if this was done?

Answer: Although many items of Laboratory equipment are 10 or more years old, new items have been progressively added as individual requirements arose and as particular devices became non-functional. Equipment purchased for the Laboratory has always been state-of-the-art when purchased. Additionally, when available, heavy duty models are normally purchased. For example, a review of the machine shop will show that industrial grade equipment, not homeowner grade, was purchased. Because the equipment is used only by the small Laboratory staff and because the Laboratory has always maintained an aggressive maintenance schedule, the life of much of the equipment has been prolonged. Use of individual items is restricted to those properly trained in its use; this precludes equipment misuse and instills a feeling of personal responsibility for those items assigned to a specific individual.

Typically, equipment purchased for the Engineering Laboratory is designed to fulfill the immediate needs of the present project, but is also expected to fulfill at least a partial need for future projects. By carefully selecting a piece of equipment and purchasing specific optional features, it is often possible to use the same piece of equipment in subsequent years. Mechanical testing devices offer a good example of this approach. A pneumatic system used to operate toasters automatically has been modified at minimal cost to serve as a crib shaker.

Additional Laboratory equipment needs are identified at the beginning of the Fiscal Year as well as at Mid-year review. The Agency acquires the priority equipment as funds are available. Currently, there are several areas where increased expenditures would be beneficial. These include additional data recording and micro-computer capability, electromagnetic radiation test equipment and improved video filming capability. The benefit to CPSC would be reflected in better staff utilization, faster turnaround for projects, more detailed data analysis through standard computer programs, and more accurate test data as a result of being capable of recording data more frequently and automatically. The estimated cost will be between $30,000 and $60,000.

I&E CAMPAIGNS

Question: Two years ago, the Subcommittee directed you to conduct evaluations of three information and education (I&E) campaigns. The objective was to change future campaigns in order to reduce the number of consumer accidents and hopefully (sic), also lessen the monies required to inform and educate the consumer. Can you briefly summarize what you learned from the three evaluations and describe the promise for meeting our two objectives?

Answer: CPSC contracted evaluations of three information campaigns conducted in FY 1984. The evaluations concluded that consumers who received CPSC informational materials learned about hazards and safety practices and took actions to improve safety in their homes. Specifically:

- o Home Heating Safety - 81% of the respondents surveyed said that as a result of reading CPSC publications on wood stoves, kerosene heaters, or gas space heaters, they now use their home heating equipment more safely.

- o Electrical Safety - Over 90% of the respondents reported that they found the CPSC electrical safety audit "somewhat useful" or "very useful," and several respondents said they took the following actions to address potential safety hazards in their homes:

    - Replaced oversized bulbs with bulbs of proper wattage.
    - Repaired electric cords.
    - Repaired wall outlets and switches, portable electric heating equipment, countertop kitchen appliances, or large appliances such as refrigerators, washers, and dryers.
    - Installed ground-fault-circuit-interrupters (GFCIs) to prevent shock.

- o Safety for Older Consumers - Post-program test scores were higher than pre-program test scores, indicating increased safety knowledge. One-quarter of the respondents reported making some changes at home as a result of the program, and one-half of the respondents said they planned to make changes such as:

    - Checking for overheated electric circuits.
    - Clearing stairways.
    - Purchasing smoke detectors.
    - Purchasing non-skid mats and rugs for bathrooms and other parts of the home.
    - Making repairs (such as replacing frayed cords).

The results of the evaluations of CPSC information campaigns suggest that consumers increase their safety knowledge and take action to address potential hazards as a result of CPSC information materials. Some of the actions taken include:

- o installation of safety devices (such as ground-fault-circuit-interrupters, smoke detectors, and non-skid mats and rugs);

o changes in the physical environment (such as moving heaters away from combustibles, replacing oversized bulbs, repairing frayed electric cords).

We know that:

o GFCIs prevent electric shock;

o smoke detectors provide early warning in case of fire;

o non-skid mats help prevent falls;

o repairing or replacing potentially hazardous products can help prevent accidents.

Therefore, we can conclude that there probably will be fewer accidents in those homes in which the changes were made.

These evaluations support the continued production and distribution of CPSC information materials to raise consumer awareness, increase knowledge, and help change behavior. The resources necessary to produce and distribute these materials increase with inflation. CPSC uses the most economical methods of material design, production, and distribution to reach the largest number of people. When possible, other Federal agencies such as HHS and the State Department reproduce and distribute CPSC materials. We note that CPSC spent approximately $37,000 to conduct these evaluations, while the program implementation costs were less than $100,000. In the future, perhaps the funds used for evaluation could be used to implement the program, thus reaching more consumers.

CHEMICAL HAZARDS AND INDOOR AIR QUALITY

Question: Last year, you testified before this Subcommittee that the quality of indoor air in residences and schools has been an area of the Commission's concern particularly in the area of the effects of structural materials, furniture and furnishings, gas ranges and stoves, and unvented gas and kerosene heaters.

The Summary of Resources table in your FY 1986 Budget justification indicates that the funding request for Chemical Hazards which includes air quality is lower than FY 1984 or your estimate for FY 1985. The staffing, as well as the funding, seems to be reduced more than any other of the hazard programs.

Would you please explain this?

Answer: The funding for the Chemical Hazards Program and for Indoor Air Quality is decreased in the FY 1986 Budget. However, many important projects continue. CPSC continues to provide a leadership role in coordinating Federal research on indoor air quality. CPSC had provided the impetus for marked improvement in emissions in home heating appliances, and has done important pilot research on volatile organic compounds in indoor air.

The Commission, while continuing current ongoing projects in the chemical hazards area, wished to review CPSC's role in the chemical hazards area. The Commission was hesitant about initiating any new project initiatives in the chemical hazards area because of concern over the long-term costs. Therefore, the Commission deferred several proposed new initiatives until the productivity and cost/benefits of current long-term research efforts could be fully assessed.

BALANCE BETWEEN HEADQUARTERS AND FIELD STAFF

Question: The field staff performs inspections; Section 15 work; in-depth field investigations of accidents; among their many activities. CPSC has always had a field staff with a strong technical backup at Headquarters. It is important to strike a proper balance between the two. The FY 1986 Budget justification proposes a field staff sized at 25% of your total staffing.

Last year, Mr. Scanlon, you indicated that a proper Commission balance would be 50% Field and 50% Headquarters.

If you increased the Field staff to half of the size of the Agency, would you not be filling rooms with consumer products sent in from the field without the technical staff at Headquarters to perform timely analysis and identification of hazard mitigation procedures?

Answer: This question does not note the fact that our Field staff also enforces our mandatory standards, as well as ascertaining levels of compliance with certain voluntary standards that the Commission monitors. The Commission Field staff also monitors major voluntary recalls to determine whether the recall is, in fact, being carried out by manufacturers. All of the voluntary corrective action plans agreed to by the Commission in Washington would be meaningless without our Field staffs' ability to assure compliance with recall decisions.

Question: Are not the scientists, technicians and legal staff at Headquarters the key players in the elimination of hazardous products?

Answer: I do not believe that we can merely characterize scientists, technicians and legal staff at Headquarters as the "key" players in elimination of hazardous products. They, and the Field staff form the team to make CPSC's projects effective.

Question: Have you revised your previous estimate of the proper balance?

Answer: No. A 50-50 balance between Field and Headquarters is an appropriate staffing target. There are many states and major municipalities without any CPSC Field representatives. We have plans to open new Resident Posts in the State Capitols of New Jersey, Virginia, and Utah and others where we can expand our cooperative programs with State and local governments. Ultimately, we can serve consumers best by communicating with them at the local level. Our State and local government contacts also expand our efforts to alert consumers of recalls, and other consumer safety messages.

EVALUATION OF THE STATE CONTRACT PROGRAM

Question: The State Contract Program provides funds which are awarded to States to conduct compliance and enforcement inspections, recall checks, and information and education activities. Although CPSC is in the process of doubling the size of this program, there has never been an impartial outside evaluation of the program.

Since there have been requests to dramatically increase the level of funding allocated to State and local consumer protection programs, the Subcommittee would like to know if it would be possible to conduct an outside evaluation of the FY 1984 and FY 1985 program using funds provided for the program?

Answer: It would be possible to conduct an outside evaluation of CPSC's FY 1984 and FY 1985 State Contract Program using FY 1986 program funds. However, we estimate that an evaluation will cost $50,000 to $80,000, and this will reduce important program activities by that amount. In addition, funding for the program in FY 1984 and FY 1985 totalled only $200,000, and the evaluation could cost up to 40% of the total two-year program and take up to one year to complete. Perhaps a more effective alternative would be to build an independent evaluation component into the FY 1986 State Contract Program. This could provide the evaluator an opportunity to develop evaluation questions as the program is being developed and implemented and determine results at its completion.

QUESTIONS SUBMITTED BY SENATOR LEAHY

LABELING

On page 16 of your budget justification, you state that:

> "In FY 1984, the Commission began to review industry compliance with its wood and coal burning stove rule, which required labeling information on installation, use and maintenance."

Is the industry complying with the labeling requirement?

Answer: Manufacturers and importers of woodburning stoves must submit all information required by the regulation to the Commission's Compliance Directorate for review. Almost 300 firms (all known manufacturers and importers) have done so. Compliance with the regulation's reporting requirement is good.

Of the initial submissions received, approximately one-half indicate full compliance with labeling regulations. At present, we estimate that almost 80% of the manufacturers and importers are meeting the requirements of the regulations. We have a program for this Fiscal Year to inspect all firms that we have reason to believe may not be complying and all firms that we think may be manufacturers or importers but have not submitted the required information. By the end of this Fiscal Year, we expect close to 100% compliance for those firms that have submitted the required information. We will also have inspected any firms that have not submitted the required information.

In addition, a "model" owner's manual is being prepared and will be sent to all manufacturers and importers to avoid all misunderstanding as to what the regulation requires.

Question: Has labeling reduced the number of deaths from stove fires?

Answer: The Commission staff is unable to determine, at this time, if labeling has reduced the number of deaths from stove fires.

The effective date of the standard was October 18, 1983. Stoves currently in the marketplace with the required labeling represent the production of only one manufacturing season i.e., 1984. We estimate it will take one or two more years before the impact of the rule can be demonstrated. In addition, fire data available to the staff are complete only through 1983 (i.e., three months after the rule became effective).

CHEMICAL/HAZARD PROGRAM

Question: On page 25 of your budget justification, you state that:

> "A 1981 report by the Office of Technology Assessment of the U. S. Congress estimated that perhaps as many as 15,000 new cancers and 8,000 cancer deaths every year may be associated with exposure to carcinogens in consumer products."

In constant dollars, since 1982, what change has there been in the chemical/hazard program?

Answer: The following chart shows the change in funding and constant dollars for the Chemical Hazard program since FY 1982.

	$(000)	Converted to '82 $(000
FY 1982	2,244	2,244
FY 1983	2,691	2,588
FY 1984	2,738	2,536
FY 1985	2,927	2,615
FY 1986	2,171	1,858

PAPERWORK BURDEN

Question: On page 9 of your justification, you indicate you will continue to reduce the paperwork burden in 1986. It has already been reduced 12 percent since 1984.

Why continue to spend resources on paperwork reduction when hazards such as backyard pools that kill 300 children a year are not being addressed?

Answer: The Commission does not allocate its resources to reducing the paperwork burden. Rather, as part of the statutory-required review of the requisites of existing regulations (rule review), the continued importance of certain testing and recordkeeping requirements is considered. More than 90% of the Commission's paperwork burden on the public is associated with the testing and recordkeeping requirements of regulations. Where they can be eliminated without affecting consumer safety, the Commission eliminates or modifies these requirements. The Commission also works to reduce the paperwork burden by careful review of surveys to ensure that the data obtained by the survey are necessary and that the information is not already available from another source.

POISON PREVENTION

Question: On page 2 of your testimony, you state that you are making "real and lasting contributions to the safety of American consumers."

The first example you cite is your "co-sponsorship" of National Poison Prevention Week.

How can the sponsorship of a public relations effort be described as a "lasting contribution"?

Answer: Poison Prevention Week, which CPSC co-sponsored with the Poison Prevention Council, involved the alerting of grandparents to a new study by the Children's Hospital of Birmingham, Alabama, showing that among children who were poisoned, more than 36% had ingested their grandparents medication. This emphasized the need for alerting grandparents to the value of child resistant closures for protection of their grandchildren.

It was our hope, by alerting grandparents now to such potential for injury to their grandchildren, that we could help them to be aware of safety options that could prevent such occurrences. Such awareness, we believe, could make a lasting contribution for safety to children by putting all grandparents on notice about these safety concerns. We hope such notice would last long beyond this one week in 1985.

BUDGET FOR PRIORITY PROJECTS

Question: On page 77 of the Budget Justification, you list the five priority projects of the Consumer Product Safety Commission.

If your budget were frozen at 1985 levels, would this list change?

Answer: The Commission's FY 1986 priority projects are fully funded. The priority project list would not change if the Commission's budget were frozen at the 1985 level.

INDOOR AIR POLLUTION

Question: In 1986, you do not include indoor air pollution as a priority project in Appendix A.

In your Budget Justification, you point out that consumer products are a significant cause of indoor pollution.

Your own studies, and studies by the National Academy of Sciences, have identified this as a major health problem.

Why is it not a priority in 1986?

Answer: CPSC is one of 15 Federal agencies working through the Interagency Committee on Indoor Air Quality to address indoor air quality issues. Many resources are being devoted to indoor air quality by State and local governments and by the private sector. CPSC is continuing to coordinate research on indoor air quality and to provide advice and guidance, based on our experience, to other agencies, State and local governments, and private sector. The designation of a project as a priority is primarily to assure full funding for the project as Agency resources are allocated through the year. There had been some concern with the large number of priority projects selected by the Commission, and a smaller number was deemed more appropriate and realistic.

CPSC still regards indoor air quality as an important public health issue and we are continuing to devote a significant portion of our resources to projects which will reduce the contribution of consumer products to indoor air pollution. CPSC is requesting approximately $960,000 for FY 1986 projects to reduce emissions into indoor air from combustion devices and pressed wood products, and to determine whether the use of certain chlorocarbons and asbestos in consumer products presents an increased risk of cancer to consumers who are exposed through the indoor air. A portion of this funding would also be used for a field study of the injuries and illnesses caused by indoor air pollution.

CPSC is addressing many important health and safety issues. In FY 1986, the Commission chose as priority projects primarily efforts to address acute hazards associated with deaths and serious injuries. The indoor air quality project addresses hazards that are not as well defined nor as well understood. Nevertheless, all the resources allocated to Indoor Air Quality during the budget deliberations of the Commission, decisions based on the merits of the projects, have been and continue to be fully committed to IAQ. The CPSC continues to join the health community in research and investigation efforts, pulling from that research information relevant to consumer product safety.

TRADE SHOWS

Question: On page 12 of your Budget Justification, you state that:

> "In FY 1985, NPI (New Product Identification) staff will put additional emphasis on identifying new products on the market which present hazards. This will be accomplished primarily through staff attendance at ten major trade shows."

Do you consider this a systematic and effective way to identify and prevent new hazardous products from entering the market?

Answer: The Commission considers staff attendance at major trade shows as one way of systematically and effectively identifying new hazardous products. This may result in keeping these products from entering the market or limiting the number of products that are on the market. Candidate trade shows were compiled based on staff experience at the show, relevance to current Commission projects and interest, and importance to the industry in question. The ten trade shows selected for FY 1985 are the most important shows in their industries, exhibit products of continuing interest to the Commission, and are likely to be valuable sources of information about new products.

Question: Is it to be continued in 1986?

Answer: Yes. The ten trade shows will be attended in 1986.

Question: If this is a new practice, how was it done in the past?

Answer: The systematic selection process for trade shows was a new practice for FY 1985. In the past, staff attended trade shows on an ad hoc basis.

CHAINSAWS

Question: On page 3 of your testimony, you mention your work on chainsaw kickback. When did the danger of chainsaw kickback come to the Commission's attention?

Answer: The Commission was petitioned by John Purtle, on March 21, 1977, to begin proceeding to develop a mandatory standard to "Minimize and Prevent Chainsaw Kickback." In June 1978, the Commission denied the petition but agreed to work with the industry in a joint effort to develop a voluntary standard.

Question: When will a safer chainsaw be available to consumers?

Answer: During the voluntary standards development process, manufacturers have continued to incorporate new safety features in the design and production of their chainsaws. As a result, most chainsaws on the market today already meet the proposed kickback requirements. Kickback injury reductions of 70% to 80% should be realized.

FLEXIBLE GAS CONNECTORS

Question: In Mr. Statler's letter to the Committee, he notes that in a limited test 40% of the flexible gas connectors tested failed the test by developing cracks. These flexible connectors are used to connect gas stoves to gas lines.

Is there no funding in FY 1986 to take action in this area?

Answer: In both FY 1985 and FY 1986 some staff months are dedicated for work on flexible connectors. During 1985, the Commission is gathering additional data on incidents involving flexible connectors. We are also working with an industry group that is considering revisions to the existing voluntary standard. Our effort in FY 1986 will concentrate on cooperation with the industry group to upgrade the safety performance of flexible connectors on a voluntary basis.

RIF

Question: If your 1986 Budget is accepted, you will have 19 fewer employees than you do in 1985.

Will this involve a RIF?

Answer: The reduction from 587 full-time equivalent (FTEs) in FY 1985 to 568 FTEs in FY 1986 will be accomplished through attrition and is, therefore, not expected to involve a reduction-in-force. At the time the FY 1986 budget was considered, our actual on-board strength was 568 FTEs.

SWIMMING POOLS

Question: On page 7 of your testimony, you list dangerous portable electric heaters as a priority activity. You note that these cause about 130 deaths per year.

According to Mr. Statler's letter, more than 300 children are killed each year in backyard drownings.

Why did you not concentrate your actions in these swimming pool related accidents which cause more deaths?

Answer: Until this year, the Commission has not acted on these pool hazards because of limited knowledge about the nature of the problem and because we were not aware of any product-related "fix" that could alleviate the situation. However, on May 14, 1985, the Commission is co-sponsoring a safety conference with the National Spa and Pool Institute to share the results of current research and to learn more about ways to improve pool and spa safety. Child drownings in pools will be a major part of the conference. Following the conference, a task force will be established that will review and, where appropriate, carry out the recommendations coming from the conference.

Furthermore, our FY 1986 Budget submission allocates resources for Epidemiological and Engineering studies of the causes of pool drownings or near drownings and possible approaches to reducing this risk.

INFORMATION AND EDUCATION

Question: In this time of tight budgets, you have to choose your priorities carefully. You will have to choose whether to put your major emphasis on "information and education" to educate consumers on how to avoid injuries or in using your regulatory powers to remove hazardous products from the marketplace. A recent article in The Yale Journal of Regulation concluded there has been no case in which information and education programs have significantly reduced the level of injury for hazardous products. In light of this fact, why do you maintain such an emphasis on education?

Answer: Section 2(b)(2) of the Consumer Product Safety Act (CPSA) states that one of the purposes of the Act is "to assist consumers in evaluating the comparative safety of consumer products." The CPSA also directs the Commission to have a "Director of Information." Clearly, we have a legislative mandate to provide product safety information to the public. As important as our statutory mandate, recent evaluation reports demonstrate that our information efforts raise consumer awareness and lead to behavior change. In FY 1984, we evaluated three consumer information efforts ("Home Heating," "Electrical Safety," and "Safety for Older Consumers"), and found in all three efforts that our programs raised consumer awareness and knowledge of hazards and changed consumer behavior to improve safe use of products. For example, consumers installed smoke detectors, ground-fault-circuit-interrupters, and slip-resistant mats as a result of our information efforts. We know that these safety measures can reduce risks of fire, electric shock, and falls.

We have reviewed the article in The Yale Journal of Regulation, and disagree with its conclusion that no information/education campaigns have produced any tangible benefits. The article itself presents data showing that the NHTSA seat belt campaign saved approximately 1,000 lives in two years at an average cost of $6,000 per life. The article also admits that a nutrition program effectively changed consumer behavior to help prevent heart disease.

We do not agree that information campaigns in all instances are ineffective. More recent evidence indicates that CPSC efforts have successfully raised awareness of hazards and improved safety behavior.

INFORMATION AND EDUCATION

Question: In your testimony this year, you prominently mention the CPSC's information and education activities. Why do you not leave such activities to the Red Cross or Volunteer Fire Departments and concentrate your efforts on your regulatory programs?

Answer: Our two priority information efforts in FY 1985 are "Nursery Equipment Safety", and "Safety for Old Consumers." The American Red Cross, Volunteer Fire Departments, and other private health/safety organizations do not have programs addressing these consumer products or hazards.

CPSC's "Nursery Equipment Safety" program addresses specific product hazards associated with cribs, baby walkers, playpens, and other nursery equipment. Where there is a CPSC standard (as in the case of cribs), our information explains the standard and encourages consumers to buy complying products. However, since many consumer's use old cribs, and since many nursery equipment products are not covered by CPSC standards, our campaign also makes several suggestions for safe use of nursery equipment. Our messages are very specific to the product and the hazard. We will be evaluating this campaign to demonstrate that our materials raise consumer awareness and lead to behavior change. The CPSC "Safety for Older Consumers" project has been hailed by every national organization concerned with older Americans. The American Association of Retired Persons, National Council on the Aging, and many other organizations have encouraged us in this project because they knew that no other organization was addressing consumer product hazards encountered by older people. Our "Home Safety Checklist for Older Consumers" has helped fill a void in many programs dealing with health and the elderly. Many groups have voluntarily reprinted our checklist for distribution to their memberships. With relatively little resource expenditure, CPSC has helped reach hundreds of thousands of older people with safety information. An evaluation of this checklist showed that it effectively raised consumer awareness of hazards and led to changes in safety behavior.

QUESTIONS SUBMITTED BY SENATOR PROXMIRE

INDOOR AIR QUALITY

Question: Last year the CPSC listed indoor air quality on its priority list and requested $1,130,000 to combat the problem. This is almost twice as much money as you requested for any other priority problem. The Consumer Federation of America recently called air pollution in homes the "No. 1 health and safety issue of the year."

This problem has obviously not been solved, so why have you removed it from your priority list?

Answer: CPSC is one of 15 Federal agencies working through the Interagency Committee on Indoor Air Quality to address indoor air quality issues. Many resources are being devoted to IAQ by State and local governments and by the private sector. CPSC is continuing to coordinate research on indoor air quality and to provide advice and guidance, based on our experience, to other Agencies, State and local governments, and the private sector. The designation of a project as a priority is primarily to assure full funding for the project as Agency resources are allocated through the year. There had been some concern with the large number of priority projects selected by the Commission, and a smaller number was deemed more appropriate and realistic.

CPSC still regards indoor air quality as an important public health issue and we are continuing to devote a significant portion of our limited resources to projects which will reduce the contribution of consumer products to indoor air pollution. CPSC is requesting approximately $960,000 for FY 1986 projects to reduce emissions into indoor air from combustion devices and pressed wood products, and to determine whether the use of certain chlorocarbons and asbestos in consumer products presents an increased risk of cancer to consumers who are exposed through the indoor air. A portion of this funding would also be used for a Field study of the injuries and illnesses caused by indoor air pollution.

CPSC is addressing many important health and safety issues. In FY 1986, the Commission chose as priority projects primarily efforts to address acute hazards associated with deaths and serious injuries. The indoor air quality project addresses hazards that are not as well defined nor as well understood. Nevertheless, all the resources allocated to Indoor Air Quality during the budget deliberations of the Commission, decisions based on the merits of the projects, have been and continue to be fully committed to IAQ. The CPSC continues to join the health community in research and investigation efforts, pulling from that research information relevant to consumer product safety.

KEROSENE HEATERS

Question: On January 29, the Consumers Union challenged the CPSC report that a new type of kerosene heater dramatically reduces dangerous air pollutants. CPSC staffer Sandra Eberle had called the heater, which Toyotomi America, Inc., manufacturers, a "technological breakthrough" in safety.

Consumer Reports said that the new heaters "still produce worrisome levels of pollutants."

In light of this criticism, are you doing any further research, and are you allowing the heaters to be marketed?

Answer: The Commission is conducting further testing of this design and any others that may also provide reduced pollutant emissions. Included in these tests will be an evaluation of the wick stop feature on one of the models tested by CU to determine if modifications would further increase the safety of this unit. The Commission continues to work with the kerosene heater industry to further reduce the possibility of consumer exposure to hazardous pollutants. The Commission continues to allow the new design to be marketed because it has made no finding that the product presents an unreasonable risk of injury. We would note that the Consumers Union report confirmed that the new design of kerosene heater dramatically reduced pollutant emissions. A comparison of the expected or "modeled" room levels of pollutants reported by Consumers Union from the new design, when compared with those CU had predicted in October, 1982, for the traditional design, confirms that the new "dual chamber" heater design produces substantially lower pollutants, especially when operated properly. That the emission rates are substantially lower has been confirmed by several laboratories.

VOLUNTARY STANDARDS

Question: Last year, at these same hearings, Chairman Scanlon, who was then a Commissioner, called for endorsement of voluntary standards.

But in a January 10th Washington Post article, Commissioner Statler said: "one potential ill effect (of endorsing the standards) is the impact on injured victims in law suits...there would be a turning away on the part of the courts in supplying adequate compensation to victims."

Then on January 17, the CPSC unanimously voted against endorsing voluntary standards and Commissioner Armstrong said that the Commission might become embroiled in industry lawsuits if they endorsed voluntary standards.

Most consumer groups, including the Consumer Union, oppose CPSC endorsement of voluntary standards. R. David Pittle, who is the Technical Director of the Consumers Union in New York said on January 10: "...It is not appropriate for an Agency with limited resources to endorse a standard it can't enforce."

In the light of this widespread opposition to CPSC endorsement of voluntary standards, why did you, Chairman Scanlon, call for voluntary standards in the February 1 Washington Post?

Answer: The referenced January 17, 1985, Consumer Product Safety Commission vote against the recognition of voluntary standards reflected a Commission decision to withdraw a staff proposal that the full Commission had previously put out for notice and comment on this issue. The original Federal Register notice dated June 19, 1984, which called for comment on the concept of recognition of voluntary standards, was also unanimously approved by the Commission, in order that we solicit public comment. The withdrawal vote on January 17 followed this public comment period. I joined my fellow Commissioners in light of some of these comments in withdrawing the staff proposal, and my statement, (a copy of which is attached), explains my reasons. I, however, was neither the sole Commissioner to propose this idea for comment, nor the sole Commissioner to favor its withdrawal.

STATEMENT OF TERRENCE M. SCANLON, CHAIRMAN
ON
CPSC RECOGNITION OF VOLUNTARY STANDARDS
JANUARY 16, 1985

The issue before us today is one of the most important, as well as difficult issues before the Commission since I have been a Member.

Our own regulations [C.F.R. 1032.4(b)(7)] point out with regard to Commission support of voluntary standards programs, one of the actions we may include is, "Encouraging state and local governments to reference or incorporate the provisions of a voluntary standard in regulations or ordinances."

It was my hope that this proposal would foster such assistance. I am dedicated to assisting the small business intense industries that meet our federal safety demands voluntarily, yet face a multitude of state and local jurisdictional demands as well in addressing the same risk of injury CPSC addresses.

Such a multitude of demands do not foster the voluntary standards process and the consumer safety that we all desire. Ultimately the cost of such duplicative regulatory demands is and must be passed along to the consumer. In such a case we all lose.

I reluctantly support withdrawal of the staff proposal before us today, aware of the current sentiment at the Commission and the problems this proposal presents. Substantial concerns were raised among others by the Federal Trade Commission on anticompetitive problems, problems such as these must be worked out. Hence, I feel compelled to vote against the proposal as it stands.

However, the recognition issue is not dead. And I am not deterred in my efforts to find a viable plan that will achieve the desirable aims but avoid the pitfalls. One avenue may lay in more positive participation in voluntary standards development, i.e., in staff voting at voluntary standards meetings. I am confident a creative solution will arise. I certainly will not rest until a solution is found.

I want to compliment the staff, the members of the ANSI/CPSC Working Group, and all of the numerous commentors for their efforts and comments on this important proposal for CPSC to promote voluntary standards.

Thank you.

COUNCIL ON ENVIRONMENTAL QUALITY

STATEMENT OF A. ALAN HILL, CHAIRMAN

ACCOMPANIED BY:

- **DR. WILLIAM L. MILLS, MEMBER**
- **MISS JACQUELINE E. SCHAFER, MEMBER**
- **KEMP R. HARSHMAN, EXECUTIVE OFFICER AND DEPUTY GENERAL COUNSEL**
- **MISS DINAH BEAR, GENERAL COUNSEL**
- **JUDY MORTON**

PREPARED STATEMENT

Senator DOMENICI. Chairman Hill, if you will sit in the middle, we will proceed.

Mr. HILL. Thank you so very much.

Senator DOMENICI. Chairman Hill, would you proceed, please?

Mr. HILL. Yes, Mr. Chairman. I have submitted a statement. I would like that to be included in the record.

Senator DOMENICI. It will be made a part of the record.

[The statement follows:]

STATEMENT OF A. ALAN HILL

Mr. Chairman and Members of the Subcommittee:

I am pleased to appear before you today and thank you for the opportunity to discuss with you the President's budget request to support the activities of the Council on Environmental Quality and the Office of Environmental Quality for fiscal year 1986. With me this morning are the other two Members of the Council -- Dr. William Mills, whom you have previously met, and Miss Jacqueline E. Schafer, our newest Member, who joined CEQ in June 1984. In addition, I would like to introduce Miss Dinah Bear, General Counsel; and Mr. Kemp Harshman, Executive Officer/Deputy General Counsel.

The President has requested an appropriation of $705,000 for CEQ for fiscal year 1986, which represents a nearly constant level of funding over a three-year period for salaries and expenses. The total budget authority for the agency, however, has fluctuated due to supplemental appropriations provided by Congress for special projects or purposes. These supplemental appropriations and their uses are detailed in CEQ's budget submission.

WATER RESOURCES RESEARCH CENTER AND INFORMATION CLEARINGHOUSE

In my testimony before this Committee last year I discussed CEQ's major contract studies to consider and define a National Center for Water Resources Research, and to define and plan a National Clearinghouse for Water Resources Information. These studies, combined under a single contract, have been completed and a final report was delivered to the Congress on September 28, 1984, before the requested due date.

The Council entered into the study in a spirit of openness without any preconceived notions about the findings. In accordance with Congressional intent, CEQ encouraged the widest possible public participation.

Four public meetings were held (two in Washington, D.C., and one each in New Orleans and Denver). The comments received at these meetings assisted the Council in refining instructions to the contractor throughout the study, and provided additional substantive material used to prepare the final report. All interested persons were given an opportunity to comment, either at the public meetings or in writing. All requests for information were honored and approximately 400 persons were placed on a mailing list.

As required, the contractor developed several alternative missions for a research center and an information clearinghouse. In proposing alternatives, the contractor recognized the size and diversity of existing programs which are fragmented among a number of agencies, organizations, and institutions. A summary of the alternative missions is provided in our budget submission.

During the course of the study a number of persons in the water resources research and information community were interviewed about their views on the center and clearinghouse and others offered written comments to the CEQ during and after public meetings on the study. There was a wide diversity of views within the research community on the purposes to be served by a new research center or on the most appropriate institutional arrangement. This does not imply that the proposed research centers are without some public support, only that no apparent consensus exists on any one option. Similarly, some public and agency support was obtained for parts of all three information options. A consensus among public reviewers, however, favored a national water information referral center as the most appropriate clearinghouse option.

The Council is pleased with the final report produced by the Chesapeake Research Consortium and with the amount and degree of cooperation demonstrated by the other federal agencies, public and private organizations, and interested citizens. Without their input and additional assistance, our task could not have been as successfully accomplished.

Let me briefly highlight some of the current efforts and future plans of the Council.

LONG-TERM ENVIRONMENTAL RESEARCH CONFERENCE

During FY 1984 and 1985 CEQ, at the request of EPA and with the assistance of the National Science Foundation, convened a series of four two-day scientific and technical panel meetings. The purpose was to address specific long-term environmental research and development (R&D) topics and to discern major scientific issues requiring enhanced government or private sector attention during the remainder of the 20th century. The panel chairmen have identified a number of issues of overriding long-term national environmental R&D importance.

The chairmen recommended that the Federal government accord long-term environmental research heightened priority and a level of support sufficient that research findings will contribute to the attainment of broad national goals. This level of support need not require additional resources; it will require, however, a continuity in many existing research programs, a continuing commitment to scientific excellence, and an adequate institutional framework.

CEQ expects to disseminate a report on long-term environmental R&D, which will include the background papers from the four panel meetings, rapporteur reports summarizing the discussions of each of the panels, together with any agency comments received on the draft report.

The recommendations of the panel chairmen, along with the draft report, were announced during a briefing held March 18, 1985.

ANNUAL ENVIRONMENTAL QUALITY REPORT

The 14th Annual Environmental Quality Report was transmitted July 11, 1984. Five thousand copies were printed for distribution to Congress, federal and state agencies and interested organizations and individuals. The Government Printing Office printed an additional 3,500 copies for their sales and Depository Library programs.

As required by CEQ's authorizing statute, the report included a review of the status and condition of the nation's environment; trends in the quality, management and utilization of our air, land, and water; the adequacy of our natural resources to meet the requirements of a growing population; and programs and activities that affect the protection of our environment and the conservation and development of our natural resources. In addition, the Council made several recommendations concerning future environmental policy.

The Council is sensitive to the importance of timeliness in making the Annual Report useful in the legislative cycle of Congress and is working towards an earlier publication date this year for the 15th Annual Report by expediting the intensive interagency review process which delayed publication last year.

NATIONAL ENVIRONMENTAL POLICY ACT

One of CEQ's primary responsibilities is its oversight of the National Environmental Policy Act (NEPA). During FY 1984, the Council was extremely active in providing oversight over the implementation and administration of the environmental assessment process. Its activities included frequent consultations, on an informal basis, with federal agencies, state and local agencies, businesses, environmental organizations and private citizens regarding both statutory matters related to NEPA and the CEQ regulations which implement the Act's procedural provisions.

The CEQ regulations provide for the referral to CEQ of federal interagency disagreements concerning proposed major federal actions which might cause unsatisfactory environmental effects. During FY 1984, CEQ received a referral from the Advisory Council on Historic Preservation regarding a proposal to partially fund the Presidential Parkway in Atlanta, Georgia. The referral raised several questions; however, the Council was most concerned with whether or not the issue presented was one of "national importance" and requested comments from the public relative to this criterion under the regulations (40 C.F.R. 1504.3(f)(4)). After review of the comments, received both at a public meeting and in writing, and a visit by the Members to the site, the Council determined that this project for a 2.4 mile highway bypass raised no issue of national importance and thus concluded the referral process in accordance with the NEPA regulations.

The Council currently has two other referrals pending. The Department of Interior has referred to us the U.S. Army Corps of Engineers' proposed Wildlife Mitigation Feasibility Study for the Tennessee-Tombigbee Waterway. CEQ held a public meeting on February 19, 1985, to address specific questions regarding this referral. In addition, the Environmental Protection Agency has referred to the Council the proposed revision of the Army Corps of Engineers' NEPA procedures.

This past year CEQ updated and published in the Federal Register appendices to the NEPA regulations, for the first time since 1980, and distributed them to agencies and interested parties. In addition, on December 31, 1984, CEQ published in the Federal Register an Advance Notice of Proposed Rulemaking to solicit written responses regarding the "worst case" regulation.

The Council plans to continue to administer its NEPA regulations; to identify and promote effective and efficient methods to implement the environmental review process; and to develop, publish and distribute a variety of informative documents which would be of use to agencies, institutions and individuals who are involved in the NEPA process.

FEDERAL ENVIRONMENTAL DATA AND MONITORING

Last year, the Council published a study conducted for CEQ by the World Wildlife Fund (headed by Russell Train) to evaluate corporate use of government information on natural resources and environmental quality. Corporate executives reported that the U.S. government is the principal source of data in this area. The study resulted in several recommendations for improvements in information quality and availability. Based on these recommendations, CEQ already has published an index of government information sources on natural resources and the environment.

We are also laying the groundwork for an interagency effort to improve the effectiveness of environmental quality monitoring programs and the dissemination of the information they yield. We intend to develop a series of work plans to improve the way in which environmental quality trends are measured.

RISK ASSESSMENT

CEQ will continue to work with and financially support the Cabinet Council Working Group on Risk Assessment, established in 1984. The Council is participating in a major review of the legal and technical underpinnings of risk assessment techniques with the objective of harmonizing the different approaches used by various federal agencies.

MANAGEMENT FUND

The Management Fund for the Office of Environmental Quality was established by its Reauthorization Act, Public Law 98-581, for the purpose of financing projects jointly sponsored by OEQ and other federal agencies and for federal interagency environmental projects, such as task forces, in which the Office participates. This Management Fund replaces the Consolidated Working Fund.

The Management Fund, divided into three program divisions, provides both definitive statutory authority and detailed accountability through regular budget review and reporting requirements. The Council has adopted written operating procedures for the Management Fund.

This concludes my prepared statement. I and the Members of the Council would be happy to answer any questions you have regarding the Council and our fiscal year 1986 appropriation request.

BIOGRAPHICAL SKETCH OF A. ALAN HILL

A. Alan Hill was designated Chairman of the Council on Environmental Quality by President Reagan in May, 1981 and was confirmed by the Senate in July, 1981.

Mr. Hill is a native Californian, making his home in San Rafael, and is a graduate of the Political Science Department of the University of the Pacific.

Prior to his appointment by the President, Mr. Hill operated his own business in San Francisco. He served for more than five years in the Reagan Administration in California, first as Assistant to the Secretary for Resources and later as Deputy Secretary for Agriculture and Services.

As Assistant to the Secretary for Resources, Mr. Hill was responsible for resource policy development for the State of California and coordinated activities of such State entities as the Departments of Conservation, Parks and Recreation, and Fish and Game, and served as Resources Secretary appointee on the Tahoe Regional Planning Agency and State Air Resources Board. As Deputy Secretary for Agriculture and Services, Mr. Hill served in then-Governor Reagan's subcabinet group and was instrumental in formulating agricultural and land use policies for the State of California and worked closely with the California Legislature on the development, passage and implementation of the Administration's policies.

Mr. Hill also served as an Assistant to the Minority Leader of the California State Senate. In that capacity, he was responsible for research and development of legislative programs advocated by the Minority Party.

Mr. Hill, father of three children, makes his home with his wife Jeanette in Chevy Chase, Washington, D. C.

BIOGRAPHICAL SKETCH OF JACQUELINE E. SHAFER, MEMBER

Jacqueline E. Schafer was appointed by President Reagan to be a Member of the Council on Environmental Quality on May 25, 1984. Her nomination was confirmed unanimously by the United States Senate. Members of the Council serve at the pleasure of the President.

Miss Schafer joined the Council after serving as Regional Administrator of the U.S. Environmental Protection Agency, Region II, in New York City. Region II includes New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. As Regional Administrator since March, 1982, Miss Schafer managed a yearly operating budget of $20 million to support 500 employees, including environmental scientists and engineers, inspectors and attorneys. The Region also awarded $25 million annually for state-delegated environmental programs and made construction grants to municipalities from a $410 million annual allotment for wastewater treatment facilities. Nearly one-fourth of the hazardous waste sites on the "Superfund" National Priorities List is located in Region II.

Miss Schafer began her career in environmental policy working as a Legislative Assistant to U.S. Senator James L. Buckley of New York from 1971 through 1976. During that time, Senator Buckley served as a member of three Senate Committees responsible for writing nearly all of the Nation's federal environmental protection statutes: Environment and Public Works, Interior and Insular Affairs and Commerce Committees. From 1977 to 1982, Miss Schafer served as a Professional Staff Member to the U.S. Senate Committee on Environment and Public Works, under the Chairmanship of Senator Robert T. Stafford of Vermont, where she was responsible for assisting the Republican Members in the development and oversight of environmental protection and economic development policy and laws. In these capacities she has contributed to a wide range of environmental legislation, most particularly the Clean Water Act, the Safe Drinking Water Act, the Marine Protection, Research and Sanctuaries Act (ocean dumping title) and the National Environmental Policy Act.

Miss Schafer was born in Greenport, New York, and grew up in New York, New Jersey, and Connecticut. She holds a B.A. in Economics (1967) from Middlebury College, Middlebury, Vermont. Before Senator Buckley's election in 1970, Miss Schafer worked on his campaign in New York City and handled all environmental issues for him. From 1967 to 1970, she was an analyst in the banking studies department and a research assistant in the research department of the Federal Reserve Bank of New York.

Miss Schafer now resides in Washington, D.C.

BIOGRAPHICAL SKETCH OF WILLIAM L. MILLS, MEMBER

On December 13, 1983, Dr. Mills was officially sworn in as a Member of the President's Council on Environmental Quality. He had been previously appointed to chair The President's Committee on the National Medal of Science by President Ronald Reagan.

Dr. Mills has served as consultant to industry and the Federal Government on matters of environmental health and opportunities for minorities. He has conducted major research for the U.S. Environmental Protection Agency and the Energy Research and Development Administration. Dr. Mills is a member of several scientific societies and has published several research reports on bioassay monitoring for occupational health. He has served as a consultant to NATO on Hazardous Wastes Management. Dr. Mills has served as expert lecturer in industrial health and safety programs for the Ministry of Occupational Health in both England and France. He is actively involved in research and training programs development for EPA and OSHA. He is also Director of the Minority Engineering Program at Vanderbilt University.

Between 1977 and 1983, Dr. Mills served as Associate Professor of Environmental and Water Resources Engineering at Vanderbilt University in Nashville, Tennessee. Previously, he was Associate Professor of Environmental Health Sciences and Engineering at North Carolina Central University in 1973-1977; research assistant and graduate student in the Department of Civil Engineering at the University of Kansas in 1971-1973; and an instructor in the Department of Biology at North Carolina Central University in 1969-1971.

He graduated from Alcorn State University (B.S., 1967), Tuskegee Institute (M.S., 1969) and the University of Kansas (Ph.D., 1973). He is married and has two children. He was born November 20, 1944 in Mobile, Alabama.

BIOGRAPHICAL SKETCH OF KEMP R. HARSHMAN, EXECUTIVE OFFICER

Kemp Harshman joined the Council on Environmental Quality as its Deputy General Counsel in January, 1983. He assumed the position of Executive Officer in November of that year and has been responsible for supervising the agency's administrative and procurement functions.

Mr. Harshman was born on November 20, 1948 in Indianapolis, Indiana and spent his formative years there. He attended Indiana University and earned a Bachelor of Arts degree with a double major in Economics and Psychology in 1971. He received his post graduate education at the University of Michigan, completing degree requirements for a Juris Doctor and a Master of Public Policy in 1975. Mr. Harshman has also been involved with the education programs of the American Management Association, both as a participant and a staff member.

Before coming to the Council, Mr. Harshman functioned in several capacities entailing both legal and management responsibilities. He has worked several years in the field of management consulting and has experience in the legal aspects of new product development. His substantive expertise is concentrated in the areas of energy development, resource conservation, and water treatment.

Mr. Harshman enjoys the out of doors in his leisure time. In 1975, he participated in a 21 day backpacking expedition in the Colorado Rocky Mountains sponsored by Outward Bound.

BIOGRAPHICAL SKETCH OF DINAH BEAR, GENERAL COUNSEL

Dinah Bear was born October 22, 1951, in Lynwood, California. She received a Bachelors of Journalism degree from the University of Missouri at Columbia, Missouri. In 1977, she graduated from McGeorge School of Law, in Sacramento, California. She practiced law with private firms in California and Kansas before coming to Washington, D.C. in 1980. She served as Deputy General Counsel of the Council on Environmental Quality from May, 1981 to November 1982; Acting General Counsel from November 1982 to January, 1983, and was appointed General Counsel in January, 1983.

She has been admitted to practice by the State Bar of California, the District of Columbia Bar and the U.S. Supreme Court. She is a member of the Federal Bar Association and the American Bar Association, Section on Natural Resources and the Environment.

LEVEL OF FUNDING

Mr. HILL. With me this morning are the two other members of the Council. On my left is Dr. William Mills, whom you previously met; On my right, Miss Jacqueline Schafer, our newest member, who joined CEQ in June 1984. In addition, I would like to introduce Dinah Bear, our General Counsel, next to Miss Schafer, and Mr. Kemp Harshman on the left, an Executive Officer and Deputy General Counsel of CEQ. The other lady at the table is Judy Morton, who is part of the staff at CEQ.

The President's request for an appropriation of $705,000 for the Council in fiscal year 1986 represents a nearly constant level of funding over a 3-year period for salaries and expenses. We have hit some high points for the Council, Mr. Chairman, in the testimony I have submitted.

I would like at this time in the interest of time to stop and go to questions.

Senator DOMENICI. You are requesting $705,000 and 13 permanent positions, This is basically the same as the 1985 level?

Mr. HILL. Yes, it is a level program.

WATER RESEARCH CENTER AND INFORMATION CLEARINGHOUSE STUDIES

Senator DOMENICI. We are going to submit a number of questions for you to answer in writing. I apologize for the brevity of the meeting, but the Senators that were supposed to be here are unable to be here, and I am taking their place for awhile. I will do my best.

First, I want to compliment you on the work you have been doing on the definition of the National Center for Water Resources Research and the Information Clearinghouse. It is not often that we expect that such efforts can be completed on time at half the budgeted amount.

Mr. HILL. Thank you.

IMPLEMENTATION OF STUDY RECOMMENDATIONS

Senator DOMENICI. What consideration has the administration given to implementing the recommendations that are in that study?

Mr. HILL. My colleague, Dr. Mills, has been working on that; he oversaw that project and did a heck of a job. Thank you for the compliment, Mr. Chairman. He has been working with interested State water resources research center directors and others.

I would like him to comment briefly on that work.

Senator DOMENICI. Please proceed, Dr. Mills.

Dr. MILLS. Thank you, Mr. Chairman. The administration supports the findings of the Water Resources Research and clearinghouse study that was conducted by the Chesapeake Research Consortium at the direction of Congress.

The administration is currently looking at options for implementing those recommendations. As we know from the study, there is no glaring and urgent need for a National Center for Water Resources Research. We have identified some areas that need to be addressed, but the existing system is more than adequate to address those problems.

The clearinghouse is another issue. There is need for a national clearinghouse for water resources and research information, and various models and proposals will be forthcoming from the university water resources research community and other water professionals in the near future for the administration's contemplation for some plan of action.

Senator DOMENICI. So you are saying the existing structure could handle the research, but some centralized clearinghouse is necessary according to your study?

Dr. MILLS. That is correct. I have continued to work with water resources research personnel and leadership from around the country, including the water resources research leadership from the State of New Mexico, I might add, Mr. Tom Barr.

Senator DOMENICI. Yes.

Dr. MILLS. We have made tremendous progress in the last 3 months in trying to identify ways to improve the capabilities of several of our State centers around the country so that the problems that the study identified as not being adequately met now can be addressed appropriately in the future with some modification of programs, strengthening of facilities and what-have-you.

PRESIDENTIAL PARKWAY REFERRAL

Senator DOMENICI. Let me go back to the Chairman now. Recently, the Council concluded a referral on the Presidential Parkway in Atlanta, GA, with a finding that the issue raised was not one of national importance. I take it that this is a threshold question in determining whether CEQ will get involved in the substance of a referral. Could you describe the extent of the process you engaged in to reach this determination, and how much greater work will be involved in conducting a full-blown referral?

Mr. HILL. Yes, Mr. Chairman. The referral we had received involved a 2.4-mile highway in Atlanta, GA, to be located on a site that was earlier acquired for a larger freeway development.

In looking at the question, we opened a record and asked for comments on the question of national importance or national significance. We had more than 300 letters on that point, and each of the three Council members visited the site individually. After looking at that question, it was quite obvious that the issues involved there were more of a local nature, which is typical of a highway alignment decision, and that this particular project did not raise any nationally significant question; that is, historic preservation.

If there is a question as to the highway being segmented and this 2.4-mile section was going to be just one piece to be added to later, then we concluded that the next segment, if it were done, would have a very adverse effect on historic areas. So we felt that a highway built that far was a decision best held in local hands, and if it went farther, it would have national significance.

TENNESSEE-TOMBIGBEE WATERWAY REFERRAL

We have just completed the referral with regard to the mitigation plan for the Tennessee-Tombigbee Waterway, which was far more intensive.

But again, we did have a public meeting; we did go into considerable detail with the two agencies involved—this was a disagreement between the Fish and Wildlife Service and the Army Corps of Engineers. We focused on a couple of questions that were very important.

One is replacement of bottomland hardwoods. In the southern part of our country, we are seeing that resource being used up at a very rapid rate. We have lost more than half of the hardwoods in the last 100 years.

We felt that the Corps should seriously enter into discussions with the Fish and Wildlife Service about replacing those bottomland hardwoods on a one-for-one basis.

The other question we addressed was whether the Corps could use intensified management on other lands at other projects which have not been mitigated because they were built in the 1950's when we had a different policy; could they use those lands, manage them more intensively, and take credit for replacement of hardwoods there. And we said yes, in this particular case, we would encourage that sort of thing.

REFERRAL WORKLOAD

Senator DOMENICI. Do you anticipate that this referral on the last situation, the wildlife mitigation, will generate any additional workload?

Mr. HILL. It had a peak that was very intensive and required work not only of the General Counsel, but another individual in the office. We have a third referral before us currently, which is a referral from the Environmental Protection Agency regarding the NEPA implementation plan that the Army Corps of Engineers has developed.

The EPA is very concerned about it. That referral has been deferred at the request of the Corps until—I think it is April 19, when we will have it formally before us.

Whether they are trying to work out those differences with EPA or not, I am not sure. Frankly, we have been preparing for this hearing, and the request for deferral came in 2 days ago. So I can't judge at this point.

We encourage the agencies to try to resolve these issues themselves. We had another potential referral with regard to Palmdale Airport, which revolves around a difference between the Air Force and the FAA.

Now, that one we have not dealt with, because the agencies have, over the past 2 years, been asking for extensions and trying to negotiate out their differences themselves. We feel the process is better served if they do that and we don't have to get involved.

NEPA WORST CASE ANALYSIS

Senator DOMENICI. With reference to the worst-case regulation evaluation, I understand that in your statement, you indicated that an advanced notice of proposed rulemaking on the worst-case regulation was published on December 31, 1984.

Mr. HILL. Yes.

Senator DOMENICI. What responses have you received on this, and how long do you estimate that might take?

Mr. HILL. We posed a set of five questions which focused on how the worst-case analysis requirement is being handled by Federal agencies. For the record, we have had a growing number of cases over the last year and a half with the court interpreting what is a very difficult area, because we are dealing with questions of lack of knowledge or situations where we know how to acquire the knowledge, but it is tremendously expensive.

In those cases, the CEQ regulations, which were adopted in 1978, require the agency going into what has become called a worst-case analysis.

We asked some basic questions about this in the ANPRM. We received 161 responses. The record was open for 30 days. We had requests to extend. We extended until February 15. The difficulty currently that we face is the decisions flowing basically from Oregon, WA, and the northwestern part of our country, which go to the question of the use of herbicides and pesticides on national forest land and a determination by the court that each of the agencies that uses those chemicals must engage in a worst-case analysis focusing on carcinogenic effects of these things.

The greater difficulty that I see in that is the court. The Ninth Circuit in San Francisco, has said that each of the agencies must develop its own knowledge and may not use the data filed with EPA under the normal registration procedure on which to base their determination.

This raises some very serious questions. As you know, the Congress will be looking at the FIFRA this year, because it is up for reauthorization.

We are trying to deal with how you handle and how you manage a process to consider these low probability but high potential impact situations where you don't have the knowledge.

We are using the responses we have received to fashion an amendment to our regulations. The Council has voted to amend the regulation rather than issue guidance.

Senator DOMENICI. So that one is going to go on for awhile.

Mr. HILL. We would hope to be finished with a draft amendment within 30 to 60 days. We are trying to give all interested parties an opportunity to offer comments, to participate and so forth, because it will become a very hot issue, as with many you face, Senator.

Senator DOMENICI. Yes, sir.

Mr. HILL. There are active advocates of various points of view.

QUESTIONS FOR THE RECORD

Senator DOMENICI. We are going to submit a series of questions to you. I would ask in the chairman's name that you answer them as soon as you can. I don't think we have an immediate deadline, but as soon as you could.

Mr. HILL. Yes, we would be happy to.

Senator DOMENICI. Do any of you want to make other comments to the committee? You introduced me to a young lady on your right, but I know her very well. She worked for the committee for 10 years, maybe.

Ms. SCHAFER. That is right.

Senator DOMENICI. You started with Senator Buckley, didn't you?

Ms. SCHAFER. Yes, sir, in 1971.

Senator DOMENICI. Nice to have you back.

Ms. SCHAFER. Thank you very much, Senator Domenici.

Senator DOMENICI. Do you enjoy your work?

Ms. SCHAFER. Yes, I do. I have been in this field for 14 years. It is amazing to see how much it has changed.

Senator DOMENICI. If you want to come back, we can use you.

Ms. SCHAFER. Thank you. It is always nice to have someplace to come home to.

[The following questions were not asked at the hearing but were submitted for response for the record:]

QUESTIONS SUBMITTED BY SENATOR GARN

USE OF FUNDS FROM RE-APPROPRIATION

Question: As you know, last year we provided a reappropriation of $175,000 to augment the Council's technical and scientific staff and for expanded NEPA oversight. We have been very concerned over the ability of your office to carry out its statutory responsibilities with the severe budgetary constraints that have been imposed.

You have yet to replace your Administrative Officer with a scientist and I understand that there is also another vacant personnel slot which has not been filled due to lack of funding.

Why was $100,000 of the re-appropriation allocated for risk assessment work of the Cabinet Council and not for additional in-house staff support?

How are your efforts to place your remaining Administrative Officer in another agency progressing?

Answer: A portion of the Reappropriation has been used to expand NEPA oversight activities and to strengthen the technical and scientific expertise of the Council. CEQ allocated $15,000 to update and publish 3 NEPA Appendices in the Federal Register, one of which had not been brought current since 1972. These Appendices contain information needed for compliance with the NEPA regulations. Also, the Council provided $60,000 in funds under an interagency agreement to acquire the services of an environmental monitoring and data specialist from the Department of the Interior. This specialist will oversee development of an inventory of Federal environmental monitoring programs and a series of work plans to implement selected recommendations of the Interagency Task Force on Environmental Data and Monitoring.

CEQ was requested by the Office of Management and Budget to reserve $100,000 of the Reappropriation to support the work of the Cabinet Council Working Group on Risk Assessment, which is comprised of 17 federal agencies. In its 1983 annual report, CEQ indicated the need for additional work in this area. The specific use of the CEQ contribution is not yet known, since the work plan for the Group has not been finalized or approved.

We have not been able to outplace our Administrative Officer. She is a highly competent professional GS-14 in the mid-range, and is very hard to place in another agency because of the high grade level.

ENVIRONMENTAL QUALITY REPORT

Question: Your statement alludes to the need for more timely completion of the Annual Environmental Quality Report. Last year, it was not transmitted until July 11. Do you have a clearer estimate as to when we might expect it this year?

Answer: The Council is sensitive to the concern expressed in the past by some members of the Congress that CEQ's annual report might be more useful if it is available earlier in the legislative cycle. There are a number of factors that influence the availability of CEQ's annual report. The Council depends on other agencies to supply draft written material on their programs. In addition, important data bases on the status of air and water quality often are not available until late in the annual report cycle. However, we are endeavoring to shorten the interagency review process that took an inordinate amount of time last year by meeting earlier and more frequently with our contributors. In addition, a Member of the Council has been assigned responsibility for overseeing the preparation of the report. We are working within our resources and the other constraints mentioned above to deliver a quality document to the President and the Congress as soon as possible.

AGENCY NEPA CONSULTATION

Question: On Pages 22 and 23 of your justification, you discuss the Council's role in the Environmental Impact Statement process -- including review and approval of agency procedures, NEPA implementation; legal interpretation and advice.

Does the Council maintain a work reporting system or a tally sheet on the numbers of inquiries and instances where specific assistance have been provided?

Answer: CEQ does not keep a log of every inquiry or request for assistance in relation to NEPA questions; however, the General Counsel has records indicating the major inquiries. We would estimate that the agency receives perhaps one to five requests a week involving substantial staff time, with perhaps eight to fifteen requests weekly which can be handled with more modest staff time. This does not include the formal referral process or major policy issues related to NEPA.

CSIN PROGRAM COMPLETION

Question: The Chemical Substances Information Network (CSIN) is designed to provide ready computer access to information on chemical substances by a broad array of users. Last year, you indicated that this system should be close to transfer to private industry by the end of FY 84. Page 29 of your justification, however, notes that this program was "severely curtailed by limited resources" in FY 85 and, in FY 86, except for monitoring the distribution and sale of two software packages, "all other activities will cease".

What work that you originally envision for this system will not be completed?

What impact will this have on the usefulness of CSIN?

Answer: CSIN was conceived as a short-term project to develop two computer software programs -- one for minicomputers and another for micro (personal) computers. The basic technology has been fully developed and is currently in use. The lack of funding was reflected primarily in the discontinuation of user support services which subsidized operation and training activities. It also resulted in the deletion of nonessential enhancements to the minicomputer version for complex search procedures and data manipulation. Since the minicomputer version is designed for time share computer operations, any impact, which is expected to be slight, will occur there. The minicomputer program performs all the basic functions without the uncompleted enhancements.

It is important to note that the microcomputer version, which is scheduled for completion by the end of the fiscal year, will have all the enhancements, including the search and data manipulation capabilities.

This technology is the state of the art for artificial intelligence and can be used to search data bases in any field, not just chemical substances. It will be offered for sale to the public through the National Technical Information Service.

MANAGEMENT FUND BUDGET ESTIMATE

Question: I am pleased that CEQ has initiated a new Management Fund in FY 85 to handle contracts and other interagency projects.

What estimate do you have for this fund's activities in FY 86?

Answer: A budget Table for the Management Fund in fiscal year 1986 is presented below. This is a current estimate of funding levels based on historical precedents, existing plans, and prospective projects.

DETAILEES TO CEQ

Question: Could you please provide, for the record, the number of non-reimbursable detailee months used by the Council during FY 84 and an estimate of the months that will be used during FY 85 and FY 86?

Please also provide the same information on detailees for which you provide reimbursement. In addition, please include information on all detailees as to the nature of their responsibilities while at CEQ and the duration of their service at the Council.

Answer: In FY 1984, the Council utilized the services of six non-reimbursable detailees for a total of 52 months. In FY 1985, CEQ is currently utilizing the services of four non-reimbursable detailees for a total of 26 months, and one reimbursable detailee for a total of 12 months. The Council has not yet arranged for any detailees for FY 1986. The nature of the responsibilities for the detailees and duration of service at CEQ is contained in the chart reproduced below.

ESTIMATE AS OF MARCH 29, 1985
OFFICE OF ENVIRONMENTAL QUALITY MANAGEMENT FUND
OBJECT CLASS BREAKDOWN
FISCAL YEAR 1986

ESTIMATED RESOURCES: 1,550,000	STUDIES DIV 100	ACID RAIN DIV 200	ALL DIVISIONS
Personnel Compensation: Full-time permanent	0	0	0
Personnel benefits: Civilian	0	0	0
Benefits for former employees	0	0	0
Travel and transportation of persons	0	26,000	26,000
Transportation of things	0	5,000	5,000
Standard level user charges	0	26,000	26,000
Communications, utilities, and other rent	0	20,000	20,000
Printing and Reproduction	0	33,000	33,000
Other services	1,250,000	178,000	1,428,000
Supplies and materials	0	7,000	7,000
Equipment	0	5,000	5,000
TOTAL	1,250,000	300,000	1,550,000

DETAILEES TO CEQ*

PARENT AGENCY	RESPONSIBILITIES	MONTHS OF SERVICE	FISCAL YEAR(S)	REIMBURSABLE
Army Corps of Engineers	Global Issues	8	1984	No
Department of Agriculture	Secretary	22	1984-5	No
Department of Agriculture	Science Policy	2	1985	No
Department of Interior	Water Research Center & Information Clearinghouse Study	10	1984	No
Department of Interior	Environmental Monitoring and Data	12	1985	Yes
Environmental Protection Agency	Annual Report Global Issues	19	1984-5	No
Environmental Protection Agency	Annual Report Global Issues	6	1984	No
Government Printing Office	Annual Report -- Printing, Binding & Distribution Public Affairs	11	1984-5	No

*As of March 29, 1985.

Questions Submitted by Senator Proxmire

ENVIRONMENTAL DISPUTE MEDIATION

Question: Mr. Chairman, your Agency is charged with mediating environmental disputes between federal agencies. How many times did you undertake dispute resolution in the last year? Were you involved in the Westway highway issue in New York? If yes, what actions did you take?

Answer: The CEQ regulations establish procedures for referrals of Federal interagency disagreements concerning proposed major Federal actions that might cause unsatisfactory environmental effects (40 CFR Sec. 1504). Under this procedure, the head of one agency may refer another agency's actions to the Council no later than 25 days after the final environmental impact statement has been made available.

During FY 1984, the Council received a referral from the Advisory Council on Historic Preservation regarding the Federal Highway Administration's proposal to partially fund a 2.4 mile Presidential Parkway in Atlanta, Georgia.

To date, during FY 1985, the Council has received a referral from the Department of the Interior regarding the Corps of Engineers' proposed Wildlife Mitigation Plan for the Tennessee-Tombigbee Waterway Project, and a referral from the Environmental Protection Agency regarding the Corps of Engineers' proposed revisions to their procedures implementing the environmental impact statement process.

During 1977 the Westside Highway project (Westway) was referred to the Council by the Environmental Protection Agency. At that time the focus of the referral was on air quality standards. The record of the Council's actions with respect to this matter are available from CEQ. Recently, two agencies (the Environmental Protection Agency and the Department of the Interior) considered referral of the project to CEQ as one of their options; neither agency proceeded with the referral.

ENVIRONMENTAL TRENDS

Question: You are required to monitor environmental trends. Could you give the Committee an idea of which areas you feel will present the biggest environmental problems over the next 10 years? Are you doing any studies on the future of the Great Lakes, groundwater pollution or carbon dioxide buildup?

Answer: CEQ has just completed a series of four two-day scientific and technical panel meetings to address specific clusters of long-term environmental research development topics and to discern major scientific issues warranting enhanced government or private sector attention during the remainder of the century. The report looks at those long-term R&D problems now identifiable. While not specifically focused on the Great Lakes themselves, the report addresses the issues related to fresh water bodies. Groundwater pollution and carbon dioxide are also the subjects of discussion in the report, a copy of which is attached.

EXECUTIVE OFFICE OF THE PRESIDENT

COUNCIL ON ENVIRONMENTAL QUALITY

REPORT ON LONG-TERM ENVIRONMENTAL RESEARCH AND DEVELOPMENT

MARCH 1985

EXECUTIVE OFFICE OF THE PRESIDENT
COUNCIL ON ENVIRONMENTAL QUALITY
722 JACKSON PLACE N W
WASHINGTON D C 20006

March 18, 1985

Memorandum

To: CEQ Interagency Subcabinet Committee on Long-Term Environmental Research

From: A. Alan Hill, Chairman A.H.

Subject: Report on Long-Term Environmental Research and Development (R&D)

I am pleased to transmit the Report on Long-Term Environmental Research and Development (R&D) in which the findings and recommendations of four expert meetings held over the past year are summarized. Panelists at each meetings concentrated on a particular research area: human health impacts and their mitigation; geochemical and hydrologic processes and their protection; environmental impacts and their mitigation; and monitoring, assessment, and environmental management. A final meeting was convened at which panel chairmen and rapporteurs and Council on Environmental Quality (CEQ) and National Science Foundation (NSF) staff met to summarize topical conclusions of the respective panels and to identify overriding or cross-cutting long-term R&D issues.

This Report is the output of the chairmen's meeting. The overall effort was requested by the Environmental Protection Agency (EPA), and CEQ's preparation of the Report was substantially assisted by the Division of Policy Research and Analysis, NSF. Additional financial assistance was provided by the Department of Energy, the National Institute of Environmental Health Sciences, and the Nuclear Regulatory Commission. The Report contains an overview of the process, the chairmen's findings and recommendations, a list of participants and discussion topics, and summaries of each panel's respective discussions and recommendations.

COUNCIL ON ENVIRONMENTAL QUALITY
CONFERENCE ON LONG-TERM ENVIRONMENTAL RESEARCH AND DEVELOPMENT

CHAIRMEN'S REPORT

March 18, 1985

EXECUTIVE SUMMARY

Scientists knowledgeable about human health and the quality of the natural environment recognize that manmade pressures placed upon natural resources, both living and nonliving, are more severe than previously suspected. Significant gaps in the existing scientific knowledge base cause or exacerbate acknowledged problems of environmental management. Long-term environmental and health research and development (R&D) is needed to resolve these scientific uncertainties, to establish baseline health and environmental parameters, to overcome lack of understanding of short-term variations in natural systems, and to identify long-term trends and relate them to their causes.

The Council on Environmental Quality (CEQ) convened a series of four two-day scientific and technical panel meetings to address specific clusters of long-term environmental R&D topics and to discern major scientific issues warranting enhanced government or private sector attention during the remainder of the century. This effort was requested by the Environmental Protection Agency (EPA) and was substantially assisted by the National Science Foundation (NSF). Additional financial assistance was provided by the Department of Energy, the National Institute of Environmental Health Sciences, and the Nuclear Regulatory Commission.

As panel chairmen, we caution that the long-term environmental and health R&D recommendations presented herein should not be viewed collectively as the comprehensive national R&D agenda for the remainder of the century; rather, they reflect those R&D issues to which substantial increased attention should be devoted. We recommend that the Federal government accord long-term environmental research heightened priority and a level of support sufficient that research findings will contribute to the attainment of broad National goals. This level of support need not require additional resources; it will require, however, a continuity in many existing research programs, a continuing commitment to scientific excellence, and an adequate institutional framework.

Principal long-term environmental R&D issues identified as warranting particular emphasis include the following:

- Improving the quality and cost-effectiveness of physical, chemical, and biological monitoring programs to test scientific hypotheses about how environmental systems operate and interact;

- Continued progress in the use of molecular epidemiology techniques to detect and measure the interaction of foreign chemicals with easily accessible normal human constituents;

- Expanded research on geohydrological processes data at the soil/water/air/hazardous waste interface;

- Identification of genetic and other factors that account for individual differences in susceptibility to environmental agents;

- Development of underlying scientific principles for evaluating the toxicity of mixtures of chemicals;

- Evaluation of consequences of human or ecological exposure to chemical substances used in, or organisms that are chemical byproducts of emerging technologies;

- Expanded collection of 10-year observations of the background physical, chemical, and ecological variations in fresh waters, oceans, and the atmosphere;

- Determination of intermedia pollutant transfer rates for description and prediction of the subsequent fate of toxic chemicals in the environment;

- Examination of the behavior and biological effects of chemicals in environmental media;

- Characterization of the role of biological and physical/chemical linkages and processes in specific biogeochemical cycles;

- Identification of the biological interactions and ecosystem processes most sensitive to global pollutants and environmental stresses;

- Development of biological inventories and baseline studies of ecosystem structures, functioning, and linkages; and

- Improvement of the scientific basis for quantitative risk assessments, and of procedures for extending them to human health effects other than cancer, such as systemic toxicity.

COUNCIL ON ENVIRONMENTAL QUALITY
CONFERENCE ON LONG-TERM
ENVIRONMENTAL RESEARCH AND DEVELOPMENT

CHAIRMEN'S REPORT

March 18, 1985

BACKGROUND

CEQ, at the request of the Environmental Protection Agency (EPA) and with assistance from the National Science Foundation (NSF), convened a series of four two-day scientific and technical panel meetings to address specific clusters of long-term environmental research and development (R&D) topics[1] and to discern major scientific issues warranting enhanced government or private sector attention during the remainder of the century. Overseeing this activity was an interagency subcabinet Committee on Long-Term Environmental Research (the Committee), chaired by CEQ Chairman A. Alan Hill. Support for the effort was provided by NSF, EPA, the Department of Energy, the National Institute of Environmental Health Sciences, and the Nuclear Regulatory Commission.

At each meeting, a panel of experts discussed a set of four substantively interrelated research topics and associated topic groupings, each of which was originated through consultation with Federal agencies. Panelists included public and private sector representatives, among whom was a rapporteur whose function was to provide a report summarizing the discussion. Background papers were prepared for each panel, and during the panel meetings the authors responded to questions. (Appendix I is a detailed listing of panel topics and subtopics.)

After all panel meetings had taken place, a fifth meeting was convened at which the panel chairmen, rapporteurs, and CEQ and NSF staff met to summarize the conclusions and recommendations of the respective panels and to identify overriding or cross-cutting long-term environmental R&D issues. This draft report is the output of that meeting. CEQ expects, following Committee review of this draft and appendices, to disseminate a report on long-term environmental R&D.

When published in final form, the CEQ report will include the background papers for the four panel meetings, rapporteur reports summarizing the discussions of each of the four panels, and this report, together with any agency comments received on the circulated draft.

THE CONTEXT

Scientists knowledgeable about health and the environment recognize that manmade pressures placed upon natural resources, both living and nonliving, are more severe than previously suspected. There is mounting evidence, for instance, that potentially health-threatening groundwater contamination is a problem of increasing concern in the United States, and that toxic chemicals in hazardous waste dumps and underground storage may pose serious health and environmental threats and create public anxiety. Analogous problems with toxic chemicals have been experienced with air and water and in the workplace.

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[1] As used here, long-term environmental R&D includes three kinds of activities: (1) anticipatory research, designed to identify potential environmental problems before they occur; (2) investigations of a continuing nature, such as ecological baseline studies or epidemiological studies, which may require a period of up to several decades to complete; and (3) fundamental research, the output of which may advance basic understanding of health- or environment-related processes.

During the past 40 years a wide variety of new synthetic chemicals have been introduced, some of which appear to pose serious acute and chronic health effects. Of similar concern is evidence of potential and perhaps irreversible damage to such important natural processes or properties as biogeochemical cycling or biologic diversity. Examples of possible changes in natural ambient levels that may be precursors of damage to health or ecosystems include the observed gradual increase in atmospheric carbon dioxide concentrations, suspected increases in atmospheric methane concentrations, possible increases in non-urban concentrations of ozone and carbon monoxide (current monitoring efforts detect primarily urban changes), observed increases in rates of species extinction in various parts of the world, and substantial ecosystem degradation in estuarine environments.

Ignorance about many scientific questions has resulted in acknowledged problems of environmental management, such as inappropriate regulation in the face of data uncertainties or heightened public anxieties. Long-term environmental and health research is needed to resolve scientific uncertainties, to establish baseline health and environmental parameters, to overcome lack of understanding of the short-term variations in natural systems, and to identify long-term trends and relate them to their causes.

For a variety of reasons, current incentives for private sector and governmental support of environmental and health R&D favor short-term approaches. Government agency research programs are generally designed to support mission goals of the agencies sponsoring them, resulting in relatively short-term research planning horizons that do not extend beyond immediate regulatory or programmatic require-ments. Similarly, corporate research efforts frequently support near-term product development strategies and are necessarily reflective of annual (or shorter) profit and loss statements. Current government and public concern over such environmental problems as acid deposition phenomena (acid rain) illustrates the fallacy in continued reliance on short-term research design. Although the potential environmental and health effects of acid particulates were pointed out years ago, relatively little research attention was devoted to following up on early studies noting these effects, and commitment of resources could not be justified on the basis of then-current regulatory strategies. Accordingly, long-term acid rain research programs were deferred; had they been undertaken a decade ago they might by now have been yielding information and predictive models of use to current regulators and policymakers.

We believe there is need for a greater resource commitment to and better direction, coordination, and interdisciplinary integration of long-term environmental and health R&D. Improvements in environmental management will flow from better characterization of environmental phenomena, increased understanding of basic mechanisms, and the development of more meaningful measures of hazard or harm assessment. Our panelists noted the need for good long-term monitoring data and accompanying quality assurance to evaluate models used for understanding processes and environmental trends. They believe that lack of validated monitoring time series data, based upon even crude health and environmental measures, has impeded the expansion of fundamental research programs. Further, they believe, the piggybacking of monitoring onto ongoing research activities may well provide useful information at little marginal cost.

We believe that modeling can be an integrating force for the environmental research community, in that the imposition of modeling requirements yields helpful insights in identifying needs and opportunities for new research. However, the use of models must be accompanied by continuing efforts to validate them. For example, in constructing quantitative risk assessment (QRA) models, it becomes clear that the unknowns in the QRA can only be satisfied by continued basic research on biochemical mechanisms. Efforts to fill modeling gaps can, in turn, provide help in determining the need for and priority of data collection activities.

General acceptance of these observations led to a consensus that the current institutional framework and organization of government resources may not assure that needed long-term research projects can be started, continued, and completed with adequate funding on a multiyear basis. Only with research continuing over many years, and for projects that extend over a substantial period of time and that are focused on fundamental issues, will the Nation be able to develop the credible and necessary expertise to better rationalize environmental management policies. Environmental science needs a critical mass of talent and resources to effectively approach the challenge of understanding complex environmental and health phenomena. The need to integrate data gathering, modeling, and environmental impact assessment and QRA efforts may require the establishment of centers of excellence, at which this critical mass of talent and resources can be assembled.

Over the long term, environmental science may provide answers to such unresolved questions as the effects of subtle changes on ecosystems, the effects of new technologies such as biotechnology and microelectronics on human health, and the effects of global contaminants on ecological processes.

CHAIRMEN'S RECOMMENDATIONS

Monitoring

Monitoring yields essential current and time series information on the status of environmental systems, information used both for environmental management and for regulatory compliance. Information gained from monitoring forms the basis for the testing of scientific hypotheses about how environmental systems operate and interact. Panelists believe that the lack of coordinated scientific resources providing institutional sophistication in environmental monitoring, modeling, biostatistics, and ecostatistics account for such problems as nonstandardization of monitoring practices and failure to monitor for parameters of greatest importance or relevance.

In the absence of validated data, modeling is frequently the only source of guidance to environmental managers for describing or predicting complex environmental events. Invariably one or more elements of necessary environmental data are missing, either because we lack the understanding or tools to measure the phenomena or because the cost of measurement is prohibitive. To the extent that monitoring data necessary for model-building are not validated or not reliable, models lack predictive value. Environmental models also frequently suffer from over complexity or from lack of standardization.

In spite of significant efforts expended on the collection of environmental data by a variety of unrelated and uncoordinated state and Federal agencies, no adequate system exists for the centralized collection, storage, maintenance, and quality control of such data. We recommend that CEQ foster an evaluation by an appropriate organization of existing physical, chemical, and biological monitoring programs (and extant data associated with them) to identify and stimulate research and development on improving the quality and cost-effectiveness of monitoring programs. Particular emphasis should be placed on determining requirements for biological and environmental monitoring, on identifying pollutants such as toxic chemicals for sampling, and on determining information and statistical requirements for environmental models.

Institutional Capability

There is an evident disparity between the current mix of institutional arrangements and resource availability to design, conduct, and manage long-term environmental research, on the one hand, and the long-term research needs identified herein, on the other. The establishment of well-funded "centers of excellence" at existing universities, such as those now supported by the National Institutes of Health and by EPA, was discussed as a possible means to redress this imbalance. The National Institute of Environmental Health Sciences represents one example of a governmental institution that has successfully supported integrated research over a long term. Another example is the Long-Term Ecological Research Program supported by NSF's Division of Biotic Systems and Resources. Laboratories owned and operated by EPA, where the research staff are government employees, provide another model. Research laboratories operated by the Federal government on contract to universities, university-based consortia, or industry-based research organizations--such as the National Center for Atmospheric Research, funded by NSF, or the national laboratories supported by the Department of Energy--provide still a third model, one at which government-sponsored research is funded on a multiyear basis.

To supplement government support, we recommend that attention be given to seeking sources of environmental and health research funding and ideas from the private sector to the extent possible, and that effort be given to coordinating government-sponsored research with research performed or supported by industry-specific organizations such as the Electric Power Research Institute, the Health Effects Institute, the Chemical Industry Institute of Toxicology, and the Gas Research Institute.

Molecular Epidemiology and Exposure Estimation

Molecular epidemiology is based upon measurement in the exposed individual of the interaction of a toxic chemical (or its derivative) with a tissue constituent or a tissue alteration resulting from exposure to the chemical. It thus provides an indirect measure of individual exposure.

There has been significant recent progress in refining means for detecting and measuring the interaction of foreign chemicals with easily accessible normal human constituents, such as chemical carcinogen interactions with deoxyribonucleic acid (DNA). It is now sometimes possible to detect a few altered DNA molecules out of the millions in a cell. Along with other developments for detection of altered chromosomes in human cells, these refinements mark important advances in our ability to detect and quantitate human exposure to foreign chemicals. Potential benefits from molecular epidemiology are so great as to justify an expansion of the national molecular epidemiology research effort. This research may eventually yield accurate markers of exposure, and information on the relationship between exposure and adverse health outcomes.

Hazardous Waste Sites

Panelists indicate that substantial geohydrological processes data gaps exist at the soil/water/air/hazardous waste interface, and that very little is known or fully understood about underlying processes. Current hazardous waste site cleanup actions are routinely commenced in the absence of knowledge about how chemicals move through the soil, how they are transformed, and how modeling can successfully be used to predict air and water contamination. We recommend that government agencies, particularly EPA and DoD, integrate well-defined research studies into plans for measurement and remedial action programs at selected hazardous waste sites.

Genetic Diversity/Susceptibility and Biological Mechanisms

Susceptibility to chemical toxicants varies widely in human host populations. Such host factors as genetic diversity, current or prior disease, sex, and age contribute to this variation. There are approximately 2,000 genetically identifiable human diseases, and there are firm theoretical foundations for the hypothesis that genetic conditions are likely to enhance (sometimes dramatically) the risk to affected individuals of developing environmentally or occupationally associated adverse health effects; however, the extent of risk enhancement is currently unknown.

It is recognized that identification of different susceptibilities as a result of genetic differences may generate or exacerbate social problems. Although

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this variation creates difficulties for the research establishment, it should not be allowed to inhibit scientific inquiry. Many of the differences in susceptibility derive from major differences in the way individuals alter (intensify or decrease) chemical toxicity through their different enzymes (active body constituents that alter foreign chemicals). We recommend that a research effort be mounted to identify genetic and other factors important for individual differences in susceptibility to environmental agents, to assess the health impacts of such differences, and to examine the means (such as differences in enzymatic activity) by which these differences become manifest.

Mixtures

Exposures of humans, other animals, and the natural environment to pollutants rarely involve single substances. Human and nonhuman organisms are generally exposed to mixtures of chemicals, whether from waste dumps, contaminated water, or ambient or workplace air. When single agents can be identified as of predominant importance, the problem is simplified. Often, however, this is not the case. Regrettably, there are no valid general rules for determining the presence of synergism in inhibitory action, and any study requiring a mixture by mixture analysis would be impossibly complex. We recommend, therefore, a major effort to define underlying general scientific principles for evaluating the toxicity of mixtures of chemicals.

Anticipating the Impacts of Emerging Technologies

Two emerging technologies--biotechnology and microelectronics--were examined. The first deals with the new field of genetic engineering, which promises to yield more efficient or new medicinal products, agricultural products, chemicals, and other products. The second involves the production of microelectronic chips with the use of a variety of virtually unstudied (exotic) chemicals, such as gallium arsenide, silicon, and halogenated hydrocarbon solvents. We recognize that there may be health and environmental consequences associated with emerging technologies, and we therefore recommend that these possible consequences be evaluated.

Fundamental Research in Fresh Water, Ocean, and Atmospheric Cycles

We lack 10-year observations of the background physical, chemical, and ecological variations in fresh waters, oceans, and the atmosphere that are adequate to distinguish natural changes from perturbations attributable to human activities. We lack continental-scale background information on historic chemicals, or even on currently important chemicals in the environmental, particularly coastal waters and the atmosphere. We are also ignorant of the normal range of variations through which ecosystems and their components pass. In addition to obtaining better information on background concentrations or biological variation, we also need to examine the processes that account for ecological variations and how pollutants interfere with those processes.

We recommend expanded collection of 10-year observations of these phenomena to better enable us to distinguish natural fluctuations from those caused by anthropogenic activities, at study sites selected to permit simultaneous observation of contaminated and close-by or ecologically similar uncontaminated areas. For study of coastal waters, several estuaries have been identified as receiving or having received significant amounts of pollutants; the fates of these pollutants should be continuously monitored. We recommend that long-term continental-scale and global-scale baseline atmospheric measurements be gathered for polluting gases such as ozone, nitrous oxides, sulfur dioxide, and hydrocarbons, and for particulates. These pollutants should be studied to determine their effects on climate, visibility, and variables that affect human health and the quality of life. We also recommend an expanded research effort to more effectively describe the transport and transformation of toxic organic compounds with respect to their physical, chemical, and biological effects in the subsurface soil and groundwater environments. Subsurface and groundwater research activities should be focused on better understanding of the interactions of groundwater with the solid phases of rocks and soils; on developing a quantitative understanding of the variation of the sorption and vapor pressure of organic compounds with soil moisture, particularly below 10-percent soil water content; and on the fundamentals of hydraulics and geochemistry for low-permeability materials. Given the expense of groundwater monitoring, research could most efficiently be coordinated with existing compliance monitoring activities.

Intermedia Transfer

Pollutants move from one receiving medium to another, and their concentrations in any given reservoir depend on the rates of these transfers. Predictions of pollutant distribution within the environment are based on quantitative assessment of these movements. At present, quantitative rate measurements of these intermedia transfers are still rudimentary.

We recommend studies to determine intermedia transfer rates for both description and prediction of the subsequent fate of toxic chemicals in the environment. Of particular interest are aerosol formation rates of chemically reactive organic pollutants and the effects of surface active agents on the air/water interface, precipitation scavenging of aerosols in the field, dry deposition as a function of topological (surface) roughness, volatilization and adsorption as a function of temperature and moisture content, and the deposition and resuspension of sediments. Determining the chemical composition of aerosol particles and the size distribution of suspended solids in the liquid phase will also help in understanding these transfer rates. We further recommend that the results of intermedia monitoring and modeling studies be used to develop screening procedures to determine under what environmental conditions and with which chemical substance characteristics it is necessary to consider intermedia transfers. We also recommend linking intermedia transport processes to the biological effects observed in receptor organisms affected by exposure to the transferred chemicals; monitored receptor organisms should include humans, commercially important species, and whole ecosystems. Finally, we recommend that anticipatory research on the intermedia nature of pollutant transfer be used in the consideration of the respective cost efficiencies of alternative multimedia control strategies. For instance, the Toxic Substances Control Act, with proposed or hypothesized amendments, should be evaluated as a basis for regulating toxic and hazardous wastes by means of multimedia control strategies.

Assimilative Capacity

In the United States billions of tons of solid waste (of which a small percentage can be designated as hazardous) are released to the land, air, surface waters, and groundwaters. Wastes also move from one medium to another and ultimately reside or degrade in various media. Assessments must be made of the cross media risks associated with waste treatment and disposal practices. Each environmental medium, and the biological communities that reside within it, is assumed to have a site-specific set of responses to different levels of waste loadings. Various wastes differ on many characteristics including toxicity, mobility, degradation rates, and their ability to be recycled or otherwise treated. Presumably some amount of certain wastes may be assimilated by the different media without adverse impacts on human health and environmental quality. Identification of the lower limits at which public health, ecosystem integrity, or the most sensitive species populations are affected is crucial to a determination of environmental quality.

Although we recognize that considerable research has been done in some of these subject areas, we recommend that research be undertaken to determine the behavior and biolgical effects of chemicals in environmental media as a basis for setting levels of release for protection of human health and environmental quality. In addition, the determination of these levels should include a consideration of such changes in the physical environment as global warming, decreases in atmospheric visibility, and their impact during extremes of temperature and moisture encountered after one- to five-decade levels of variations.

Global Biogeochemical Cycles

Global biogeochemical cycles are essential to the maintenance of the biosphere. Continuous interaction between biotic and abiotic components of the Earth distinguishes it from other planets and, thus, the term biogeochemical cycling. We recommend the conduct of long-term fundamental studies to characterize the role of biological and physical/chemical linkages and processes in specific biogeochemical cycles (for example, in carbon, nitrogen, phosphorus, sulfur, and oxygen cycles), as well as in their interactions with each other and with climate to build on the results of previous research.

Global Pollutants and Impacts on Ecological Processes

Significant gaps in the environmental sciences knowledge base reflect our ignorance of cause/effect relationships between global pollutants and ecological processes. We recommend the conduct of long-term studies to identify the biological interactions and ecosystem processes that are most sensitive to specific past, present, and anticipated global pollutants and environmental stresses. The outputs of such studies might be helpful in clarifying the impact of pollutants on the total biosphere, and on global chemical processes.

Fundamentals of Ecosystem Structures and Processes

In order to identify those ecological phenomena that are related to the sustainability of ecosystem resources, and especially to the conservation of biological diversity, there is a need for long-term biological inventories and baseline studies of ecosystem structures and functioning. Especially needed are studies of processes that link different ecosystem types (for example, suburban/urban, agricultural/aquatic, industrial/agricultural linkages). We recommend the identification of ecosystem sites that can be studied and the establishment and maintenance of a national network of representative ecosystem sites, both those that are relatively undisturbed and those that are intensively managed.

Quantitative Risk Assessment

Quantitative risk assessment (QRA) has come to play a major role in regulatory processes and in risk management generally. Current QRA techniques are generally acknowledged to be crude and to lack the precision commensurate with the importance attached to the regulatory decisions frequently based on them, decisions that may be of great social and economic consequence.

Scientists now believe that improvements in QRA techniques are more likely to come from better understanding of biological processes than from improvements in mathematics. Far too little is now known, for instance, about basic pharmacodynamic and environmental mechanisms of toxic effects, about virtually any health (other than cancer) or ecological effects, and about actual exposure patterns; and about the potential of short-term biological screening to provide early prediction of effects. Further studies are needed on the independent validation of risk assessments, better understanding of decision processes, identification of scientific principles used in selection of assumptions and criteria, determination of the criteria used as a basis for risk assessment priorities, and improving the understanding of risks. We recommend that particular research attention be given to improving the scientific basis for risk assessments, and to procedures for valid extension to human health effects other than cancer, such as systemic toxicity.

COUNCIL ON ENVIRONMENTAL QUALITY

CONFERENCE ON LONG-TERM
ENVIRONMENTAL RESEARCH AND DEVELOPMENT

CHAIRMEN'S REPORT

APPENDIX I

PANEL TOPICS AND PANELISTS

Panel Subject	Topic Subjects
HUMAN HEALTH IMPACTS AND THEIR MITIGATION	Human Physiologic/Genetic Diversity
	Molecular Epidemiology
	Monitoring of Effects of Exposure to Health Hazards
	Human Health Impacts of Current and Emerging Technologies
GEOCHEMICAL AND HYDROLOGIC PROCESSES AND THEIR PROTECTION	Surface Water/Groundwater Processes and Pollution
	Land/Soil Processes and Pollution
	Atmospheric/Oceanic Processes and Pollution
	Multimedia Toxic Substance/Hazardous Waste Research
ENVIRONMENTAL IMPACTS AND THEIR MITIGATION	Global/Biosphere Impacts
	Local Ecological Impacts
	Ecological Diversity
	Environmental Impacts of Current and Emerging Technologies
MONITORING, ASSESSMENT, AND ENVIRONMENTAL MANAGEMENT	Data Generation, Collection, Analysis, and Interpretation
	Risk/Impact Assessment Techniques
	Modeling and Forecasting Techniques
	Environmental Management Approaches

HUMAN HEALTH IMPACTS AND THEIR MITIGATION

Human Physiologic/Genetic Diversity

Topics

"Priority Needs in the Development of Epidemiological Techniques That Account for Human Physiologic and Genetic Variability"
Author: Dr. Mark Skolnick, University of Utah Medical Center

"The Roles of Human Physiologic and Genetic Variability in the Development and Expression of Pollutant-Related Diseases"
Author: Dr. Elliot S. Vesell, Pennsylvania State University

Molecular Epidemiology

Topics

"Novel Approaches to the Investigation of Pollutant-Related Disease: Molecular Epidemiology"
Author: Dr. Frederica P. Perera, Columbia University

"The Value of Molecular Epidemiological Techniques in Quantitative Health Risk Assessment"
Author: Dr. Dale Hattis, Massachusetts Institute of Technology

Monitoring of Effects of Exposure to Health Hazards

Topics

"Problems in Demonstrating Disease Causation Following Multiple Exposures to Toxic or Hazardous Substances"
Author: Dr. Robert Dixon, U.S. Environmental Protection Agency

"The Value of Health Registries in Monitoring Pollutant-Related Disease"
Author: Dr. Paul Schulte, National Institute for Occupational Safety and Health

Human Health Impacts of Current and Emerging Technologies

Topics

"Improved Methods for Discerning Health Impacts of Current Technologies"
Author: Dr. James M. Robins, Harvard University

"Anticipating the Potential Health Impacts of Exotic Chemicals Associated with Emerging Technologies"
Author: Dr. Daniel T. Teitelbaum, Denver Clinic Medical Centers

"Anticipating the Potential Health Impacts of Emerging Technologies: Biotechnology"
Author: Dr. Daniel Liberman, Massachusetts Institute of Technology

HUMAN HEALTH IMPACTS AND THEIR MITIGATION

Chairman

Dr. Norton Nelson	New York University Medical Center

Rapporteur

Dr. Edward J. Calabrese	University of Massachusetts

Panelists

Dr. Manning Feinleib	National Center for Health Statistics
Dr. Perry J. Gehring	Dow Chemical Company
Dr. Bernard Goldstein	U.S. Environmental Protection Agency
Dr. Irving Johnson	Eli Lilly and Company
Dr. James L. Liverman	Litton Bionetics
Dr. Brian MacMahon	Harvard School of Public Health
Dr. Mortimer L. Mendelsohn	Lawrence Livermore Laboratory
Dr. David P. Rall	Nat'l. Inst. Environ. Health Sciences
Dr. Ellen K. Silbergeld	The Environmental Defense Fund

GEOCHEMICAL AND HYDROLOGIC PROCESSES AND THEIR PROTECTION

Surface Water and Groundwater Processes and Pollution

Topics

"Improving the Knowledge Base on Surface Water and Groundwater"
Author: Dr. Wayne A. Pettyjohn, Oklahoma State University

"Protection of Surface Water and Groundwater Resources"
Author: Dr. Nathan Buras, University of Arizona

Land/Soil Processes and Pollution

Topics

"Identifying Knowledge Gaps on Land/Soil Processes: Hazardous Substances and the Land/Soil Resource"
Author: Dr. Louis J. Thibodeaux, Louisiana State University

"Advancing Knowledge on Protection of the Land/Soil Resource: Assimilative Capacity for Pollutants"
Author: Dr. Raymond C. Loehr, University of Texas

Atmospheric/Oceanic Processes and Pollution

Topics

"Priority Needs for Improving the Knowledge Base on Atmospheric Processes"
Author: Dr. Stephen Wofsy, Harvard University

"Advancing Knowledge of Pollutant Effects on Coastal Ecosystems"
Author: Dr. John Teal, Woods Hole Oceanographic Institution

Multimedia Toxic Substance/Hazardous Waste Research

Topics

"Scientific, Legislative, and Administrative Constraints to Multimedia Control of Toxic Substances and Hazardous Wastes"
Author: Leslie Sue Ritts, Esq., Morgan, Lewis and Bockius

"Modeling of Pollutant Transport in a Multimedia Environment"
Author: Dr. Yoram Cohen, University of California

GEOCHEMICAL AND HYDROLOGIC PROCESSES AND THEIR PROTECTION

Chairman

Dr. Edward D. Goldberg	Scripps Institution of Oceanography

Rapporteur

Dr. Michael S. Connor	U.S. Environmental Protection Agency

Panelists

Dr. Keros Cartwright	Illinois Geological Survey
Professor Henry P. Caulfield, Jr.	Colorado State University
Dr. Michael A. Champ	U.S. Environmental Protection Agency
Dr. Robert A. Duce	University of Rhode Island
Dr. Bruce A. Egan	Environmental Research and Technology, Inc.
Ms. Frances H. Irwin	The Conservation Foundation
Dr. Charles L. Osterberg	U.S. Department of Energy
Dr. Frederick G. Pohland	Georgia Institute of Technology

ENVIRONMENTAL IMPACTS AND THEIR MITIGATION

Global/Biosphere Impacts

Topics

"Maintaining the Integrity of Global Cycles: Nutrient Elements, Water, and Energy"
Author: Dr. William R. Emanuel, Oak Ridge National Laboratory

"On Toxins and Toxic Effects: Guarding Life in a Small World"
Author: Dr. George M. Woodwell, The Ecosystems Center

Local Ecological Impacts

Topics

"The Role of Basic Ecological Knowledge in Environmental Assessment"
Author: Dr. Stephen G. Hildebrand, Oak Ridge National Laboratory

"The Role of Basic Ecological Knowledge in the Mitigation of Impacts from Complex Technological Systems: Agricultural, Transportation, and Urban Systems"
Author: Dr. Orie L. Loucks, Holcomb Research Institute

Biological Diversity

Topics

"Habitat Diversity and Genetic Variability: Are They Necessary Ecosystem Properties?"
Author: Dr. Elliott A. Norse, The Ecological Society of America

"Increasing the Precision of Indicators of Change in Natural and Man-Impacted Ecosystems"
Author: Dr. Frieda B. Taub, University of Washington

Environmental Impacts of Current and Emerging Technologies

Topics

"Improved Methods for Discerning the Environmental Impacts of Current Technologies"
Author: Dr. Nicholas Clesceri, Rensselaer Polytechnic Institute

"Anticipating the Potential Environmental Impacts of Emerging Technologies"
Author: Dr. Martin Alexander, Cornell University

ENVIRONMENTAL IMPACTS AND THEIR MITIGATION

Chairman

Dr. John E. Cantlon	Michigan State University

Rapporteur

Dr. Lev R. Ginzburg	State University of New York

Panelists

Dr. John W. Firor	National Center for Atmospheric Research
Dr. Marvin B. Glaser	Exxon Research and Engineering Company
Dr. Robert C. Harriss	Nat'l. Aeronautics and Space Admin.
Dr. Dean L. Haynes	Michigan State University
Dr. Francis C. McMichael	Carnegie-Mellon University
Dr. Joseph F. Malina, Jr.	University of Texas
Dr. John M. Neuhold	Utah State University
Dr. J. C. Randolph	Indiana University

MONITORING, ASSESSMENT, AND ENVIRONMENTAL MANAGEMENT

Data Generation, Collection, Analysis, and Interpretation

Topics

"Development of Environmental Data Bases and Inventories"
Author: Dr. Don W. Hayne, North Carolina State University

"Improving Methods of Data Analysis and Interpretation for Environmental Management Programs"
Author: Dr. Richard E. Sparks, Illinois Natural History Survey

Risk/Impact Assessment Techniques

Topics

"Improving Quantitative Health Risk Assessment Techniques"
Author: Dr. Lester B. Lave, Carnegie-Mellon University

"Improving Qualitative and Quantitative Environmental Assessment Techniques to Support Environmental Management"
Author: Dr. Peter E. Black, State University of New York at Syracuse

Modeling and Forecasting Techniques

Topics

"Long-Term Research on Simulation Models Applied to Environmental Management"
Author: Dr. Gordon L. Swartzman, University of Washington

"The Role of Forecasting Methodologies in Approaches to Environmental Management"
Author: Dr. John F. Ficke, The IT Corporation

Environmental Management Approaches

Topics

"The Role of Interdisciplinary Environmental Research in Natural Resource Management"
Author: Dr. David Pimentel, Cornell University

"Innovative Environmental Management Approaches for Cost-Effective Control of Industrial Residuals"
Author: Richard A. Ferguson, Esq., The Skylonda Group, Inc.

MONITORING, ASSESSMENT, AND ENVIRONMENTAL MANAGEMENT

Chairman

Dr. Richard M. Dowd	R. M. Dowd & Co.

Rapporteur

Dr. Richard N. L. Andrews	University of North Carolina

Panelists

Dr. A. Karim Ahmed	Natural Resources Defense Council
Dr. Bruce N. Bastian	Shell Oil Company
Dr. Edward J. Burger	Georgetown University Medical Center
Dr. James W. Gillett	Cornell University
Dr. Raphael G. Kasper	National Research Council
Dr. Franklin E. Mirer	United Auto Workers
Dr. Glenn W. Suter	Oak Ridge National Laboratory
Dr. Milton Russell	U.S. Environmental Protection Agency
Dr. Jaroslav J. Vostal	General Motors Research Laboratories

APPENDIX II

Summary Report
of the
Expert Panel Meeting
on
Human Health Impacts and Their Mitigation

INTRODUCTION

The meeting on Human Health Impacts and Their Mitigation was included in the series of expert panel meetings because the preservation and protection of public health and well-being are the ultimate goals of environmental management strategies practiced by governments and by the private sector. The four topic areas examined in this meeting were:

- Human Physiologic and Genetic Diversity;
- Molecular Epidemiology;
- Monitoring of Effects of Exposure to Health Hazards; and
- Human Health Impacts of Current and Emerging Technologies.

THE CONTEXT

The intent of this meeting was the development of consensus judgments on long-term environmental R&D needs in the topic areas mentioned above. The expert panelists agreed that development of such consensus judgments depended on clear statement of the problem at hand. We stated our sense of the problem in the form of four critical questions:

- What are the major knowledge gaps related to the maintenance of good health and prevention of disease in the topic areas examined?
- What research can be identified as promising to fill the identified gaps and reduce the likelihood of future disease and injury?
- What precedent steps may be required in order to make possible research more directly relevant to the knowledge sought? and
- What are the priorities among the R&D recommendations so assembled?

Specific suggestions with respect to these four questions were contained in the background papers for each topic area examined. In addition, we were asked to address the generic question of how the necessary R&D might be done. We considered the processes of funding support and institutional mechanisms, namely, intramural and extramural funding, grants, contracts, cooperative agreements, and other special support mechanisms. We stress the importance of interdisciplinary collaboration and the desirability of incentives for better connections among investigators in laboratory sciences, clinical research, and epidemiology. Such collaborations are especially desirable if scientists are to fully benefit from new and emerging basic research in genetics and molecular epidemiology.

We were also asked to comment on where the responsibilities lie between the public and private sectors for long-term research (both environmental health research and environmental research) and to comment on the institutional framework for the R&D activities proposed in this review. Our response to these issues is general and rarely prescriptive. Research in pursuit of long-term goals must of necessity be concerned with fundamental questions of science. As an example, the role of oncogenes is an important current topic in the evaluation of human carcinogenesis, but it would have been impossible to approach without the preceding extensive basic research leading to an understanding of deoxyribonucleic acid (DNA) structure and function.

Exposure, Dose, Effects, and Endpoints

Throughout our discussion, we searched repeatedly for a suitable schematic to outline our notions of mechanism. The starting point rests on the four rough stages at which environmental toxicological processes can be observed:

- Exposure--the ambient condition bringing the organism into contact with the hazard (for example, toxicant concentrations in air or water);
- Dose--the internalized quantity of the hazard (for example, serum concentration, body burden, or amount of a toxicant in a particular organ or cell);
- Effects (markers)--intermediate biological effects that are either a step in the toxicologic process or a parallel manifestation of effect; or effects that are useful as indicators of exposure or dose, as predictors of toxicity, and for studies of mechanism (for example, chromosome aberrations, mutation, cell killing, enzyme activity); and
- Endpoint--the ultimate toxicologic effect (for example, a disease such as cancer, heart disease, or early mortality or morbidity).

Between each two of these stages there are intermediate stages or processes. Thus between exposure and dose there is entrance of the agent into the organism, absorption, distribution, and--depending on the circumstances--metabolic activation and deactivation, and excretion. Between dose and intermediate biologic effect there may again be the various pharmacologic processes that bring the agent to the effector site and thus activate it into its effective form. Also there are various mechanisms that may cause lesions, such as DNA or protein adducts, that repair lesions, and that cause lesions to progress to an observable biological response. Between the intermediate or surrogate biological response and the ultimate disease there are numerous and generally unknown steps in the toxicological process.

At each stage and for many of the transition processes there may be markers of what is going on; that is, observable chemical or biological properties that can serve as markers. Examples are numerous and include, using cancer for illustration,

- Monitors of ambient concentrations;
- Personal exposure devices;
- Tracer, experimental, or trial measurement of uptake, activation, excretion, or transport;
- Measurement of adducts in cells or organs, or of free chemical or chemical products in body fluids;
- Measurement of actual DNA repair or of repair capacity;
- Characterization of the metabolic profile of an individual or group;
- Assay of gene mutation, chromosome aberration or sister-chromatid exchange;
- Assay of cell transformation;
- Precancerous markers, and the analogous markers for other disease processes;
- The full battery of clinical laboratory tests for early disease or abnormality; and
- Screening methods for disease detection.

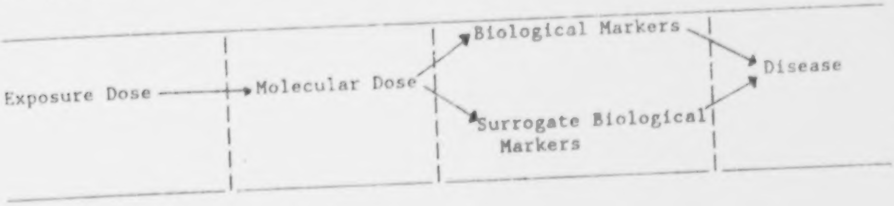
The Panelists are in general agreement about these concepts, and more detail for this kind of reasoning can be found in the background papers by Perera, Hattis, and Dixon. We cannot, however, reach consensus on a common terminology, in part because of a priori preferences for particular terms, and in part because several of the stages are conceptually broader than any of the terms on which the Panel could agree. Some choices of terms are summarized in Figure 1. Panelists are agreed that detection capability is greatest at the "exposure" end of the continuum and weakest at the "clinical" (disease) end.

FIGURE 1

Continuum From Exposure to Endpoint

Exposure →	Dose →	Effects/Response →	Endpoint
Exposure Dose	Internal Dose Biologically Effective Dose Molecular Dose	Preclinical Response Biological Dose Surrogate Biological Dose Biological Marker Exposure Indicator	Disease Clinical Effects

The preferred (but not unanimous) version of our schematic is as follows:



Physiologic and Genetic Diversity

Susceptibility to chemical toxicants varies widely in human populations. Such differences have not always been adequately taken into account in the study of environmentally related health impacts. Many host factors, such as current or prior disease, sex, age, and genetic diversity, contribute to differential susceptibility to chemical toxicants.

There are approximately 2000 genetically identifiable human diseases, as well as numerous genetic modulators of biochemical, physiological, and immunological human responses. Some genes are known to enhance individual response to environmental agents, but for the most part, whether and to what extent genetic factors predispose persons to, or protect them from, environmentally-induced disease is not known. Developing research methodologies in the field of genetic epidemiology offer considerable promise in assessing the associations posed above.

Techniques such as the use of DNA probes as genetic markers can lead to the development of an accurate genealogical assessment of how a gene is distributed in a population. This has the advantage of identifying persons who could serve as part of a cohort for a subsequent epidemiologic study to quantify the extent to which particular genetic constitutions may be at increased risk to environmental agents such as mutagens and carcinogens. This technique offers a clear advance over present approaches, which are limited to using genetic probabilities to estimate the relationships between genes and delayed effects.

There are excellent theoretical foundations to support the hypothesis that genetic factors are likely to enhance the risk of affected individuals developing environmentally or occupationally induced adverse health effects. However, the extent to which supporting data are available from studies with appropriate predictive animal models or human epidemiologic studies is highly variable. Examples of likely mechanisms are heritable DNA repair deficiencies, such as ataxia telangiectasia and xeroderma pigmentosa and metabolic variants such as glucose-6-phosphate dehydrogenase (G-6-PD) deficiency, acetylation capacity, and spectra of mixed function oxidase capacities.

Of the human genetic conditions identified as potentially enhancing susceptibility to environmental and occupational toxins, only G-6-PD deficiency leading to hemolysis has a demonstrable causal history of enhancing susceptibility to certain industrial pollutants. Even in this instance, there is a lack of precise dose-response relationships. No adverse effects have ever been adequately related causally to the statistical association between levels of pollutant exposures and the extent of hemolysis occurrence. In addition, the role of potential confounding variables, such as nutritional and overall health status, has never been adequately assessed. The lack of predictive animal models for many human hereditary disorders indicates a research need in what is a new and promising area of investigation.

Molecular Epidemiology

The use of integrated chemical or biomolecular measurements of individuals within the context of properly designed epidemiological studies (that is, molecular epidemiology) provides a powerful and sensitive means for linking individual exposure and response with outcomes (See Figure 1). It should be noted here that the distinction between injury and "change" is not always sharp or readily made. Although most research identified as being "molecular epidemiology" has dealt with cancer, this concept could apply to the study of many other disease entities as well.

A principal research thrust associated with the field of molecular epidemiology is that molecular biologists/toxicologists and epidemiologists should identify subfields in which complementary skills could be effectively integrated and applied to solving complex environmental health problems. What is important here is the development of institutional mechanisms that assist basic scientists and toxicologists in working collaboratively with epidemiologists.

Research needs include the development of better characterizations of sensitivity, specificity, time-course, predictive value, reproducibility, and dose-sensitivity of molecular markers. Research in molecular epidemiology requires an aggressive development of a biochemical molecular approach to assess chemical exposure and chemical-induced injury; establishment of the relationship between these measurements and effects (molecular interactions, biological markers, and subsequent disease) is an essential element of such research.

The use of quantitative risk assessment (QRA) of health effects depends on development of models that are hypothetically consistent with present understandings of the process of carcinogenesis within an individual (that is, a multistage process), but such models may have the current limitation that, despite being aimed--to the extent possible--at the most sensitive group, they do not deal explicitly with variation in host susceptibility.

Molecular epidemiology may be useful in the development of more biologically plausible models for use in quantitative risk assessments. At the present time, molecular epidemiology would be helpful in providing a better quantification of variation in response to exposure to environmental contaminants. This type of quantitative characterization of the responses of the human incorporated into quantitative risk assessment models could play a significant role in improving their reliability.

Although there is a need to establish the most biologically plausible predictive models for low-dose cancer risk predictions, both frem the perspective of the process of carcinogensis in the individual and from the perspective of the variation in response within the highly heterogenous human population, there is also a need to validate these predictions whenever possible. Expanded use of pharmacokinetic data can also improve cross-species extrapolation.

Research on alternate and adjunct approaches to methods for QRA also merits extension; this should include QRA for endpoints other than cancer. In addition, the use of molecular epidemiology can provide measurements of effective dose and early preclinical response to toxicants that may be predictive of health outcomes. This approach should ultimately provide more precise estimates of human risk of disease associated with low level exposures than are now possible with existing quantitative risk methods.

Banks of Biological Materials

The Panel discussed the usefulness of various tissue banks. The resolution of several questions was considered crucial before a bank is established. Examples of these questions are the following:

- What specific hypotheses are to be addressed by the study of these tissues?
- How should the samples be stored and access to them assigned?
- What type of materials (for example, whole blood, plasma, red cells, DNA, fibroblasts, lymphoblastoid lines, placentas, tumors) should be maintained? and
- What types of populations are to be studied?

The primary task is to evaluate the value of banking tissues from various ongoing studies or projects. A second task is to decide if specific studies should be undertaken to establish additional cell banks. We believe that a thorough review of existing tissue and cell banks should be undertaken, and that maximum use should be made of these resources before developing and supporting further efforts in this area.

Multiple Exposure

One of the most important environmental health questions of continuous concern has been the issue of predicting the effects of mixtures of toxic agents on biological systems. Human exposure to environmental agents is almost always multiple, and the potential for interactions among the multiple exposures is great. The biological activity of these agents must be defined in the laboratory and monitored in human populations. Dose-response relationships must be developed, species comparisons attempted, and thresholds for effects (when they exist) established. Use of biological dosimeters of exposure will greatly facilitate this effort.

It was pointed out that major gaps in our knowledge of the effects of multiple exposure include the lack of models that enable us to predict interactions, short-term tests to identify hazardous complex mixtures, and epidemiological studies on the effects of mixtures. Because most known biological interactions between chemicals have only been investigated at relatively high exposures, particular attention needs to be given the dose dependency of these interactions.

The Panel felt that a pragmatic evaluation of numerous combinations of chemicals is not likely to be useful for establishing the foundation upon which accurate predictions of untested combinations could be made. The best avenue for developing predictive models is thought to be best derived from the elucidation of mechanisms of toxicity.

Registries

Registries may be an important resource in the assessment of the potential effects of environmental agents on human health. They provide a useful source of information for analysts to tap in evaluating specific hypotheses concerning exposure/outcome associations, and in identifying high-risk populations, exposures, and specific outcomes. Exposure-type registries should not be permanent fixtures, as is sometimes the case, but should have a defined term based on fulfillment (or nonfulfillment) of purpose.

Most emphasis on registries has rightly been placed on the development of outcome and exposure registries. However, there is a need to develop registries of genetic groups potentially at high risk, for research purposes only. For example, the availability of a registry of persons carrying one or more defective repair genes would allow the health consequence of these deficiencies to be determined, and would provide a resource of subjects for incorporation in other studies of dosimetry, markers, and occupational and environmental effects. It was also suggested that a registry of biochemical receptors would be a useful tool for anticipating agents likely to have high-level biological effects.

The operation and administration of registries can be performed by private or public institutions. This has been effectively demonstrated with outcome registries, such as cancer registries. Generally, for outcome registries, those who use the information should have a primary role in the data collection or maintenance of the registry. The situation is less clear with exposure registries. These are newer and may not initially have designated users. For these types of registries, governmental entities might be the best choice for overseeing or maintaining them. However, major users should be actively involved in their advisory bodies.

The legislation that established the Agency for Toxic Substances and Disease Registry designated it as a Federal Government responsibility. Individually identifiable information, in Federally-operated registries, is subject to the protection of the Privacy Act and hence generally not available under Freedom of Information Act requests. Thus, governmental operation imposes certain limitations.

Exposure registries need not be exclusively confined to governmental operation, but since they may be used to circumscribe populations with potential risk prior to the formulation of specific hypotheses, the impetus for maintaining them might be weaker without governmental support.

Clinical Epidemiology

In addition to the strong emphasis placed on the need for research in the subject area of molecular epidemiology, it was recognized that the practice of clinical epidemiology can also make significant contributions in elucidating the etiology of occupationally- and environmentally-enhanced disease in a cost- and time-effective manner. This is particularly true when the risk of disease is high and a relatively small sample size can suffice. Such research could make use of special techniques (See, Robins et al.) to enable researchers to establish the occurrence of clinical changes. Use of this type of clinical epidemiological study could indicate whether a serious public health concern exists and whether more extensive cohort studies are necessary. An example of the utility of such a research methodology was presented in which a clinical study of lithographers revealed that six of seven displayed aplastic anemia as a result of exposure to glycol ethers. The existence of such a study established the link between glycol ethers and aplastic anemia, but it would require data to extend this linkage to a quantitative risk assessment.

Emerging Technologies

Assessing health hazards of emerging chemical and biological technologies presents a major challenge to environmental health professionals.

Microelectronics: The problem is exemplified by the semiconductor industry. Although traditionally viewed as nonpolluting, the microelectronics industry uses several thousand chemical agents, including a number of exotic chemicals with limited toxicological data bases. Process advances in microelectronics technology are in a state of continuous change and new processes (such as laser etching and focused ion implantation) bring new toxicological concerns. These and other forthcoming advances in the microelectronics industry provide an opportunity to initiate human health studies from the very first use in industry.

The need to evaluate the toxicological hazards associated with novel advances within the microelectronics industry should serve as a model for the close cooperation between the emerging chemical technologies and the toxicological community.

Biotechnology: The field of biotechnology represents another set of unique and important health-related research challenges. By definition, biotechnology is the application of a biological system to technical and industrial processes; as such it represents the integration of molecular biology with chemical and process engineering. The principal health-related concerns have centered on the potential for microorganisms, as altered by genetic engineering, to prove harmful. Assessing these concerns has been hindered by the difficulty not only of quantifying the probability of a novel occurrence, but also by uncertainty as to the type of damage that may occur.

Even when the organisms employed in an industrial process are thoroughly characterized, the concern about possible health risks will continue. A recombinant DNA sequence may be characterized in great detail, but its entrance into the human ecosystem may provide unforeseen and important assessment questions.

It should be emphasized that natural organisms highly modified by genetic selection have been used safely for a long time in industrial applications. The issue, then, is whether artificial insertion of genes by genetic engineering is sufficiently different to bring a new scale and spectrum of risks. The present reality is that there is a lack of data to support or deny concerns about genetically-engineered organisms in the open environment. A major health-related challenge in the area of technology as applied to genetic engineering is the need to address this lack of a data base from which reasonable policy judgments on the course of biotechnology could emerge.

Research Funding Considerations

Within the context of limited governmental research budgets, there is the natural inclination for peer reviewers and agencies to shy away from funding labor-intensive studies, especially as they pertain to long-term studies. However, given the chronic exposure and long latency periods of environmentally induced diseases, long-term studies in this field are often the most likely to yield outcomes of a quantitative and relevant nature. Because such studies have the possibility of providing a large return on investment, they should not be discriminated against in the funding process. As with all studies, the long-term, labor-intensive protocols must be able to pass the peer review process as established by granting agencies.

Both contracts and cooperative agreements have tended to become so awkward administratively as to discourage many investigators. In addition, there is little incentive on the part of investigators to bring novel ideas to Federal agencies in the context of contracts, given the necessity of issuing a Request For Proposals that requires the investigator to release an idea to the competitive, open research market. The reopening of the sole source mechanism in appropriate cases could remedy this dilemma.

The Panel believes that the Federal funding agencies should develop a flexible program for funding certain studies, in a very short time frame, for which relatively unique and transient opportunities present themselves and in which the research benefits are potentially high. Although the provision of initial funding could help the investigator acquire the baseline data, he would then be obligated to submit a full proposal for continued funding of the project. This process would allow the supporting agency to take advantage of a unique circumstance with a modest investment of money, while requiring the investigator to perform in an acceptable and peer-reviewed way for continued support.

RECOMMENDATIONS

We elected not to assign priorities to our recommendations. In addition, we adopted an underlying principle, related to informing the public, that is critical to effective implementation of our recommendations.

This principle states, "Society should be informed of the rapid technological changes in the biomedical sciences and their implications for human health and safety to provide a sound basis of understanding and to allay needless anxiety."

Specific Panel recommendations are as follows:

Human Physiologic and Genetic Diversity

We have adopted the following recommendations relative to the great heterogeneity that exists in physiologic and genetic makeup of human populations:

- Seek better understanding of how human genes interact with environmental factors to produce or modify disease;

- Initiate a major Federally-funded effort to study the basis and significance of differential susceptibility. The effort should be concerned with genetic factors affecting toxicity, as well as with development, aging, nutrition, lifestyle, and prior disease. The knowledge generated would be of considerable value to many sectors of society, including the various regulatory agencies in their standard-setting methodologies;

- Extend occupational and environmental health studies beyond Caucasian males to include women and non-Caucasian racial groups, given that most current health-based criteria used to support exposure standards are derived from studies with Caucasian males. This is needed because the workforce composition is changing;

- Extend the use of DNA probe/genealogical studies to identify useful cohorts in environmental and occupational health studies;

- Develop *in vitro* assays for the phenotypic identification of heterozygotes, which are possibly at increased risk to agents causing environmentally induced disease;

- Combine the use of DNA probe/genealogical studies and *in vitro* assay techniques to identify high-risk and susceptible groups within the population; and

- Continue review of test protocols for the Environmental Protection Agency, the Food and Drug Administration, and other appropriate agencies with special considerations for groups at potentially increased risk.

Biochemical and Molecular Epidemiology

The wide range of opportunities available in the fields of biochemical and molecular epidemiology leads us to make the following recommendations:

- Monitor by molecular epidemiological methods specific human populations (such as workers, smokers, or chemotherapy patients) exposed to potential carcinogens. Monitor both for intrinsic information and for methods development;
- Refine measures of functional impairment and cumulative damage and correlate these with markers;
- Explore utility of tissue banks in biochemical epidemiology in order to permit retrospective studies; and
- Seek ways to facilitate collaboration between epidemiologists and molecular biologists.

Clinical Epidemiology

We have adopted the following recommendation as a means of capturing the potential contributions of epidemiologic approaches:

- Actively pursue clinical epidemiological studies as an initial phase in the establishment of a data base to support subsequent risk assessments.

Health Registries

Recognition of the value of health registries in documenting evidence of health dysfunction leads us to make the following recommendations:

- Support research for the mapping of genes and create repositories. This follows from the observation that large-scale genealogical studies and data bases have a unique opportunity to determine gene/environment interrelationships in the development of numerous human diseases;
- Increase availability of medical and Federal financial records, such as Social Security and Internal Revenue Service records, for research studies in ethical ways;
- Improve access to health and safety data in industry;
- Encourage and extend the Surveillance Epidemiology and End Results (SEER) program;

- Evaluate possibility of self-selection bias in exposure registeries and its influence on epidemiological study outcomes; and
- Explore utility of establishing a registry of receptors, including their occurrence and characteristics.

Exposure

Reliable exposure assessment is a vital component in quantitatively relating exposure to disease outcome. Consequently, we make the following recommendation:

- Develop better methods for quantification of exposure. Two of the most important limitations affecting the statistical strength of epidemiologic studies are the quality and quantity of exposure data. There is a need to direct research toward the development of better biological indicators of exposure. These include markers of molecular dose and early response to toxic substances at the cellular or molecular level. Environmental monitoring also needs improvement; the correlation of biological markers with environmental measurement (exposure dose) should be tested.

Mechanisms of Action

Comprehensive knowledge of mechanisms of action is invaluable information. Therefore we recommend that the following actions be taken:

- Extend study of cell membrane and cytosolic receptors as aids to understanding of toxic action of chemicals; and
- Support parallel pharmacokinetic laboratory studies in animal models and persons already occupationally exposed, in order to attempt to validate animal model predictions of human responses, and understand mechanisms of toxicity.

Quantitative Risk Assessment (QRA)

QRA approaches are increasingly being incorporated in regulatory and other environmental management strategies. Because of the need to improve and clarify the methodology for QRAs, we make the following recommendations:

- Intensify efforts to improve and validate QRAs,in particular to improve methods for extrapolating data from laboratory animals and other test systems to determine QRA in humans;
- Seek ways to include role of genetic diversity in QRAs; and
- Explore development of QRAs for endpoints other than cancer and genetic effects.

Mixtures

Individuals or populations are rarely exposed to agents singly; therefore, we make the following recommendations:

- Intensify study of the mechanisms of known chemical interactions in and on biological systems; and
- Downgrade the utility of pragmatic testing of chemicals studied in combination.

New and Emerging Technologies

Although sometimes characterized as having few or benign impacts, the existence of novel technologies poses the potential for serious health impacts. Thus, we have adopted the following recommendations:

- Monitor genetically engineered organisms that have been designed to survive in the environment; and
- Exploit the opportunities for the study of new and exotic potentially toxic chemicals by initiating studies on first usage.

APPENDIX III

Summary Report
of the
Expert Panel Meeting
on
Geochemical and Hydrologic Processes
and Their Protection

INTRODUCTION

The meeting on Geochemical and Hydrologic Processes and Their Protection was included in the series of expert panel meetings because the observed changes in the environmental media of air, soil, and water are key indicators of the existence and ultimate effects of hazards to environmental quality and human health. Many connections with the long-term environmental research and development (R&D) topics addressed in the other panel meetings were evident. The Panel was charged with addressing long-term environmental R&D needs in four topic areas:

- Surface Water and Groundwater Processes and Pollution;
- Land/Soil Processes and Pollution;
- Atmospheric/Oceanic Processes and Pollution; and
- Multimedia Toxic Substance/Hazardous Waste Research.

THE CONTEXT

Knowledge of geochemical, atmospheric, and hydrologic processes enables us to understand how chemical substances we have released to the environment, or that we encounter from natural sources, are transported or transformed and thus inadvertently become part of the air we breathe, the food we eat, or the water we drink. These processes also affect the survival of plants, animals, and humans living at sites distant from where the substances were initially discharged, or initially existed. Environmental risk assessment requires an evaluation of exposure to chemical substances and of the nature and magnitude of effects associated with that exposure. Both categories of knowledge are essential to our capability to predict the consequences of the release of chemical substances to the environment. In order to predict exposure to chemical substances, environmental managers must determine quantitatively where these chemicals are discharged and how they are transported through and transformed by the environment. Long-term research is needed to define the relationships between geochemical, atmospheric, and hydrologic processes and the biological receptors of the transported chemical substances. We cannot preserve the health of biological communities or humans without knowledge of these transport and transformation processes.

Each year billions of tons of solid waste material, of which a small percent can be designated as "hazardous," are produced in the United States. Whether via landfills, surface impoundments, direct surface applications to land, incineration, fugitive emissions, or direct or indirect release to air, surface waters and groundwaters, these wastes are discharged to and ultimately reside or degrade in the three environmental media. Many wastes degrade rapidly. Some, however, persist or are transformed into substances that can cause damage.

Waste management strategies have assumed that soils can be used for interment of toxic and hazardous substances. But we still lack rudimentary knowledge of the quantitative importance of fundamental soil processes. We need to make an investment now in increasing our knowledge of these processes to prevent future waste disposal problems, problems that are serious in consequence. Wastes discharged improperly can increase our daily exposure to chemical substances that may be acutely or chronically toxic, or these substances may cause long-term environmental change to living or nonliving resources. Furthermore, these are long-term problems. Even with waste reduction processes, we will continue to generate some amount of residuals that require disposal.

Each medium has a specific capacity to assimilate some amount of the wastes it receives without unacceptable adverse impacts to human health or environmental quality. There are numerous examples, however, in which each of the environmental media has been overloaded in certain areas. In addition, there are transfers between the environmental media that may cause unanticipated environmental degradation. In some cases, the transfer from one medium to another has been the measure of concern; an example would be the movement of material from the soil to groundwater. This and other examples are described below.

Soil/Groundwater Manifestations

Large quantities of wastes are discharged to the soil from homes, cities, and industries. Researchers surveying hazardous wastes managed in 1981 under the authority of the Resource Conservation and Recovery Act estimated that of the total hazardous wastes disposed, 3 million wet tons were placed in landfills, 19 million tons were released to surface impoundments, and 32 million tons were discharged into deep injection wells. In addition, several million tons of hazardous wastes removed from hazardous waste sites over the next decade will need to be treated. Other less-visible threats to our soil/water resources include approximately 1.9 trillion gallons annually from septic tanks, 4.8 million dry tons/year of municipal sludge, and an unquantified amount of leakage from underground chemical storage tanks, particularly from the large number of gasoline storage tanks dotting our landscape. Although we have some information regarding the thousands of drinking water wells that have been forced to close, we have very little information concerning the magnitude of risks facing our groundwater supplies, both in terms of information on the status of whole aquifers and comprehensive data on concentrations of all organic compounds of concern.

Atmospheric Manifestations

The behavior of the atmosphere itself is affected by trace contaminants. Among these are methane, nitrogen oxides, and ozone. The atmosphere receives emissions from a number of different sources while providing rapid transport and dilution. Emissions have been increasing at a rapid rate from the surface of the Earth such that each year 10^8 tons of methane and 10^7 tons of nitrogen oxides are released to the atmosphere, a large percentage attributable to human activities. The emissions to the atmosphere of nitrous oxide and methane exceed known removal processes, and atmospheric concentrations of these pollutants are expected to increase during the next 10-50 years. Analysts examining data from polar ice cores have indicated that methane concentrations have doubled in the last 400 years. We are just beginning to understand the effects of these emissions, but it is expected that increased concentrations of nitrous oxide, methane, and other radiatively active gases will contribute to the warming of the Earth's climate. Ozone concentrations in rural U.S. locations are also thought to have increased, doubling since the 1950s, and episodes of high concentrations that can blanket the eastern United States are sufficient to cause damage to agricultural crops in laboratory experiments.

Atmospheric manifestations have terrestrial consequences as well. Ozone, nitrogen oxides, and sulfate deposition have all been hypothesized to be responsible for the decline of forests in Central Europe and the eastern United States. Environmental exposure to airborne lead, benzene, and trichloroethylene, as well as to ozone and other substances, may pose significant health risks.

Coastal Ocean Manifestations

The open ocean can provide an enormous amount of dilution to minimize the risks presented by waste disposal, particularly those wastes dominated by high concentrations of metals or nutrients. Coastal estuaries, however, act as containment basins, collecting sediments and contaminants from rivers, direct discharges from coastal municipalities and industries, and atmospheric deposition. Several billion gallons of sewage effluent are discharged to our coastal waters each day, and millions of tons of solid wastes are dumped into the ocean each year.

The potential for estuaries to retain wastes can be seen in those estuaries that have become hazardous waste sites such as Commencement Bay, WA, and New Bedford Harbor, MA. In other estuaries, contamination of fish with kepone, PCBs, or dioxins has forced the closure of commercial and recreational fisheries, and bacterial contamination forces the closure of about one-quarter of the Nation's shellfish beds each year. Eutrophication in the Chesapeake Bay has been blamed for the decline of sea grass communities that serve as nursery areas for fish and help protect the coastline from erosion.

General Principles of Geochemical and Hydrologic Processes Research

The Panel's major findings fell into four general categories:

- The importance of an integrated approach to environmental problems;
- The need for long-term environmental research;
- The necessity of developing predictive models for determining the stresses placed on geochemical and hydrologic processes by different waste loadings; and

- The importance of determining the efficacy of different institutional strategies for environmental management.

Integrated Approaches: The Panelists endorse an integrated approach to the environmental problem of waste management, and feel that the approach must be

- integrated across the environmental media of air, soil, and water, and subcompartments within those media;
- integrated across substances present in the environment, both in how interactions between chemicals may affect the way these substances are transported and transformed in the different media, and in how chemical interactions influence their effects on health and environmental quality; and
- integrated across disciplines addressing these problems, including disciplines in the natural sciences and social sciences concerned with the natural and institutional processes for controlling risks associated with alternative environmental management strategies.

The importance of the transfer of contaminants between environmental media has been documented repeatedly: volatilization of chlorinated organics from hazardous waste sites, sewage treatment plants, or contaminated shallow aquifers; the transfer of substances from air to soils and surface waters through precipitation and dry deposition; and the removal of contaminants from surface waters and groundwaters by sorption to soils or sediments and their subsequent rerelease during resuspension and desorption.

Although the results of intermedia transfer studies have often been qualitatively demonstrated, quantitative rate measurements of these processes are still rudimentary. Transfer rates of particular interest are aerosol formation of chemically reactive organic pollutants and the effect of surface active agents on the air/water interface, on precipitation scavenging of aerosols in the field, on dry deposition as a function of surface roughness, on volatilization and adsorption rates as a function of temperature and moisture content, and on the rates of deposition and resuspension of sediments. Determining the chemical composition of aerosol particles of different sizes and the size distribution of suspended solids in the liquid phase will also help in understanding these transfer rates.

The other CEQ Panels have recommended the study of long-term effects attributable to chemical interactions in complex mixtures of effluents. We endorse those recommendations. From preliminary results of ongoing studies, analysts believe that the movement of high concentrations of complex mixtures of wastes through soil differs markedly from laboratory models, in which the movement of dilute concentrations of single compounds is measured. Leaking containers at hazardous waste sites or accidental spills are prime examples of the occurrence of such high concentrations of complex chemical mixtures.

The study of geochemical and hydrologic process across different media obviously requires knowledge from a broad range of disciplines from soil science to atmospheric chemistry. The Panel also recognizes that natural science research of geochemical and hydrologic processes must be supplemented by social science research to facilitate interpretation of natural science results into laws and regulations that can be implemented and enforced.

Long-Term Environmental Research: In addition to the need for greater emphasis on integrated approaches, there are long-term needs for the study of transport and transfer processes and their biological consequences within each medium. We use the phrase "long-term environmental research" in all three definitional senses considered by CEQ: research that is fundamental in nature, that provides a continuing baseline, or that anticipates future research needs.

Fundamental Processes: The Panel finds that long-term research of fundamental processes is particularly necessary in the subsurface soil/groundwater environment. Our knowledge base is least advanced for this medium and currently inadequate to protect public health and the environment in all cases. Specific research is needed to better describe the transport and transformation of organic compounds considering hydraulic, biotic, and abiotic aspects in both homogenous and heterogenous soil matrices. For instance, water plays a dominant role in the soil environment, but we do not have a quantitative understanding of the variation of the sorption and vapor pressure of organic compounds with soil moisture, particularly below 10 percent soil water content. In addition, we know very little about the fundamentals of hydraulics and geochemistry for low-permeability materials, yet low-permeability sites are selected as optimal locations for the disposal of hazardous wastes. In addition, we need more information about the hydrologic properties of crystalline rocks and the importance of networks of fractures because most deep injection wells are located in these types of formations.

Continuing-Baseline Studies: The Panel finds that the short-term intensive studies at waste disposal sites can be linked with some longer term studies conducted concomitantly. The Panel emphasizes deficiencies in "continuing-baseline," long-term research, especially continental-scale studies in coastal waters and the atmosphere. In these media, there is more knowledge of environmental processes, but insufficient background information on historic or even present concentrations of many important chemicals.

We are also ignorant of the normal range of variations through which ecosystems and their components pass in coastal waters. Without knowledge of background concentrations or biological variation, we have a very difficult time assigning causes to small pollution impacts, because we cannot distinguish them from natural variations. Once we are certain that a measurement is outside the normal range for the system, we will also need to study the processes that have caused such effects and how pollutants interfere with those processes. Without knowledge of the normal range of variation, we are unable to determine unambiguously that something has happened to the system. Long-term observations, on the scale of decades, are necessary for the oceans and the atmosphere.

Anticipatory Studies: Long-term coastal ocean and rural atmosphere monitoring stations could serve as "anticipatory long-term research" vehicles for identifying actual environmental problems at an early stage. Past experience is an indication that surprises are likely, and it is our intent that monitoring programs exist side by side with research programs to explain the monitoring observations.

Data Quality: Because of the expense associated with collecting long-term environmental data, the Panel notes that compliance and monitoring data at existing hazardous waste sites and other industrial waste sites, such as Superfund sites, could be used for research if scientists were involved in the initial design of data collection programs. Data gathered for environmental management, whether for litigation, for determination of environmental trends, or for policy development, must be valid for its proposed uses. In addition to our concern about the precision and accuracy of measurements, we must assure that the data collected are appropriate to the needs the data must serve. Monitoring data could be used in answering research questions by careful initial design of sampling programs. Research questions concerningthe transport of chemicals away from the site are, in turn, germane to regulatory concerns about risks posed by waste sites.

Assimilative Capacity Predictive Models: The Panel deliberated extensively over the usefulness and meaning of the concept of "assimilative capacity" of the environmental media to process waste loadings. We recognize that recycling and re-use, pretreatment, and process and product substitutions are the cornerstones of any waste management strategy. We note that the term "assimilative capacity" can have different meanings among disciplines. Many of these differences can be attributed to media characteristics. For instance, in containment media such as soils and some coastal estuaries, assimilative capacity refers to the amount of material added to a system before the system begins to leak, releasing the wastes to the outside environment. In dispersive environments, such as the atmosphere and open ocean, this physical sense of the term would refer to a rate of waste loading that is sufficient to allow waste concentrations to be diluted to the range of background variation outside of a mixing zone. Especially for soils, we know relatively little about assimilative capacity, with the exception of the assimilative behavior of soils with respect to certain metals.

Both of these transport-based definitions also may include, although they have not usually in the past, consideration of the extent to which these waste loadings are transformed by physical, chemical, or biological processes to other substances, the rates of transformation, and the degree to which these transformed substances accumulate in the environment.

Transport-based definitions of assimilative capacity require knowledge of geochemical, hydrologic, and transformation processes. Assimilative capacity has a further biological definition in engineering design of "the amount or rate of waste addition that does not cause unacceptable adverse impacts to the public health or to the environment." This effects-based definition of assimilative capacity requires additional information on long-term biological effects of pollutants on receiving media.

The determination of assimilative capacity in environmental management requires the development of predictive models. We believe that a useful first step for model formulation is to use simple models coupled with monitoring to permit model validation. Initial case studies should emphasize pollutants that exist primarily in one environmental state, whether gaseous, liquid, or particulate. In addition, compounds should be chosen that have similar residence times in each medium.

Institutional Arrangement Needs

Although we believe that an intermedia approach is necessary for proper waste management, we note that extant laws and regulations relating to environmental protection largely focus upon single media. Changing institutional arrangements to allow more of an intermedia perspective will present problems requiring long-term political and administrative research as well as research in the technical areas discussed above. Multimedia regulation may be possible by only slight modifications of existing institutions or may require extensive changes. In appraising alternative institutional means for achieving multimedia control, the feasibility of legislative and regulatory adoption and implementation must be determined. Better efforts are required to understand the political science and policy of environmental legislation. One method to improve our understanding of the efficacy and feasibility of multimedia control is to explore our historical experience with environmental protection at the legislative and administrative levels.

Institutional Research Needs

We believe that the sorts of intermedia, interdisciplinary, long-term research that we have discussed above are not adequately addressed by the current institutional structure. For instance, no academic institution has a curriculum that is adequate for the preparation of its students for tackling intermedia issues. Additionally, the measurement of substances in any medium over long time periods will be quite difficult, as evidenced by case histories of past attempts. Example are the long-term measurements of carbon dioxide in the atmosphere.

Improved institutional arrangements are needed to assure adequate funding, conduct research, and apply the research results to the solution of environmental problems. We have not identified what sort of institutional structure would be most appropriate. We have agreed that important attributes of the institutions conducting research are that they be interdisciplinary, nonpolitical, and capable of taking a broad, integrative view. Several panelists cite the EPA's Centers of Excellence or the National Center for Atmospheric Research as possible models.

RECOMMENDATIONS

In developing our recommendations, the Panel concurs with a seminal principle for research on media processes and their protection: "our environmental media--air, soil, and water resources--are vital to life on this planet and inextricably linked; our goal is to preserve our soil, air, and water resources and their productivity; these resources will always serve as an ultimate sink for wastes, though the amount and hazard associated with current waste inputs can be reduced; and protection of these resources is economically more reasonable than allowing contamination and then attempting restoration." We also believe strongly that the private sector should play an increased role in the improvement of existing monitoring techniques and protocols. We emphasize the importance of information transfer to environmental managers in both government and industry.

Integrated Approaches

We recommend the following research activities:

- intermedia transfer rates should be determined in an intermedia modeling/monitoring program that is focused on intermedia transport as a function of different physical parameters;

- results of intermedia modeling/monitoring programs should be used to develop screening procedures to determine for which environmental conditions and chemical characteristics it is necessary to consider intermedia transfer;

- effects of chemical interactions on transport processes should be studied; and

- there should be a linking of these transport processes to the biological effects seen in receptor organisms affected by exposure to the chemicals, whether they be humans, commercially important species, or indicators of the health of whole ecosystems.

Fundamental Processes

We recommend the following research activities:

- Research on transport and transformation processes should be conducted as part of site-specific field studies. Extrapolation to field situations from laboratory results has been extraordinarily difficult to date, and until more general principles are revealed, site specificity will remain a perplexing problem for soil/groundwater studies. We recommend that existing hazardous waste sites and other industrial waste sites and well-functioning Resource Conservation and Recovery Act (RCRA) sites be investigated as candidates for study. Given the expense of groundwater monitoring, we believe that research can most efficiently be coordinated with compliance monitoring at existing sites at an early stage of development of the sampling plan. Besides exiting sites, older sites can also be explored similarly to the way archaeologists exhume ancient civilizations, reconstructing important processes occurring years earlier through the analysis of chemical residues. We recognize that there may be legal constraints on such a research approach because of such questions as liability, but we believe the idea is worth pursuing; and

- Atmospheric research should be aimed at understanding fundamental processes controlling tropospheric biogeochemical cycles on a global and continental scale. These processes include studies of source and sink processes for atmospheric gases, particles, and research on photochemical reactions.

Continuing Baseline Studies

We recommend the following research activities:

- For coastal waters, several small estuaries (for example, Buzzards Bay, MA, South San Francisco Bay, CA, Mobile Bay, AL, or Trinity Bay, TX) should be selected to determine the mass balance of contaminants while establishing the natural biological communities residing in these estuaries and the effects of contaminants on those communities. Mass balances should also be conducted on coastal areas that have historically received large waste loads. Improved collection of data about chemical release is necessary to do this. As yet, we have not been able to construct satisfactory contaminant mass balances for any estuary. This problem should be most tractable in small estuaries, where it is only necessary to consider relatively few processes; and

- For the atmosphere, long-term baseline measurements (at least 10 years) should be collected for the most important pollutants. These would include ozone, oxides of nitrogen and sulfur, and methane--on both a continental and global scale. Baseline rural atmospheric measurements, in particular, are emphasized because they currently lie outside the range of responsibility of the present institutional structure. These data are needed to define the current state of the atmosphere, to shed light on important source mechanisms, and to allow determination of long-term trends.

Assimilative Capacity

We recommend the following research activities:

- Information should be developed regarding the amount of waste generated and disposed into each of the environmental media, the amount of reduction available under the above options, and whether exposure could be reduced by handling the waste in another medium. We also recommend that new methods be evaluated for their potential to detoxify municipal and industrial wastes. For example, wet-air oxidation, an aerobic thermophilic process, may be technically and economically feasible for treatment of concentrated organic wastes; and

- Regional evaluation methods and techniques should be developed for predictive purposes, including the development of single-media and intermedia models. There is an immediate need for methods to screen out inappropriate or outmoded waste sites and to verify pollutant transport models. Models appropriate for one set of uses or conditions may be totally inappropriate in a slightly different context. It is important to ensure that the model is valid for the uses that are required of it. We are concerned that the models not require unrealistically extensive data collection. The data collection requirements for many existing models quickly become impractical under normal field settings.

Institutional Arrangement Needs

We recommend the following research activities:

- Respective costs and benefits of multimedia control as a regulatory strategy should be characterized and appraised in comparison to single- or dual-media alternatives. Pollutants that can be more effectively controlled through multimedia control strategies should be identified. It may be that a multimedia approach is only necessary for a small number of cases;

- Alternative strategies of multimedia control should be characterized and appraised, with such strategies defined by (a) alternative goals and objectives; (b) alternative institutional means to achieve goals and objectives; and, (c) requirements for scientific and other technical inputs. In particular, there should be an evaluation of the usefulness of approaches such as that embraced in the Toxic Substances Control Act as a basis for regulating toxic and hazardous wastes by means of multimedia control. For instance, case studies of EPA's Office of Groundwater and the evolution of the Groundwater Strategy, or of EPA's current acid rain activities, could yield valuable insights into administrative constraints to toxics integration efforts, because each of these potential subject areas involves toxic problems with multimedia dimensions.

APPENDIX IV

Summary Report
of the
Expert Panel Meeting
on
Environmental Impacts and Their Mitigation

INTRODUCTION

The meeting on Environmental Impacts and Their Mitigation was included in the series of expert panel meetings both because of growing public concern over the compatibility of economic growth and environmental quality and because of the need for greater predictive capability concerning the role of environmental resources (physical and biotic) in influencing human well-being. The topic areas that served as foci for background papers for and discussion at the meeting were

- o Global and Biosphere Impacts;
- o Local Ecological Impacts;
- o Biological Diversity; and
- o Environmental Impacts of Current and Emerging Technologies.

THE CONTEXT

Environmental concerns about the abandonment, use, and expansion of existing technologies, and about the deployment of new technologies, will continue to influence both governmental and private decisionmaking. These concerns have both national and international dimensions and are expected to continue well into the foreseeable future. Our capacity to estimate ecological and environmental risks is not sufficient to insure against either costly, and possibly irreversible, damage to essential biogeochemical cycles or preventable extinctions of endangered species and ecosystems.

This panel is convinced that serious deficiencies in risk assessment capabilities can only be alleviated by a substantial increase in the amount, quality and diversity of long-term ecological research. Our discussions have been focused on the kinds of long-term environmental research that we believe should be given high priority. We also note structural and personnel dimensions of long-term environmental research that need attention.

A major point of consensus among Panelists was the need to evaluate institutional options for providing stable support for interdisciplinary long-term environmental research. Stability in the funding for this interdisciplinary research was viewed as crucial in attaining the goals and recommendations set forth by the Panel.

Global and Biosphere Impacts

The Earth's biogeochemical cycles are essential to the maintenance of the biosphere. The continual transfer of chemical elements between biotic and abiotic components of the biosphere distinguishes the Earth from other planets and motivates use of the term biogeochemical element cycling.

Earth's element cycles involve major reservoirs, including the atmosphere, oceans, and terrestrial and aquatic ecosystems, that are coupled by physical, chemical, and biological processes. Earth's climate is strongly influenced by the physical, chemical, and biological composition of these reservoirs, and climate, in turn, influences element cycling in the biosphere. These element cycles are also linked to each other by ecosystem processes--the pool size and flux of one element depends on the pool sizes and fluxes of other elements. These two feedback loops play significant roles in maintaining habitability of the planet.

Equilibrium (or steady-state) budgets for global cycling of the major elements (carbon, nitrogen, phosphorus, and sulfur) have been widely published and recently well reviewed. Missing values are frequently estimated based on the assumption of equilibrium or as a fixed ratio to values for other elements. Thus, such numerical values are largely judgmental. It is, therefore, important to realize that the published data on equilibrium global budgets for elements may be misleading in suggesting responses to perturbations. The relative importance of various cycling processes and elemental fluxes may be quite different in projecting responses to a perturbation than they are in describing budgets under natural circumstances.

The carbon cycle is the only cycle whose global scale response to a large-scale perturbation, fossil fuel use, has been analyzed in any detail. It makes a great deal of difference, however, what assumptions are made concerning the biotic reservoir during the period of enhanced release of fossil CO_2 into the atmosphere. Even in this case, model-based estimates of carbon uptake by the oceans are, in general, too low to balance with observed changes in atmospheric CO_2 concentrations.

Because of the strong interactions between biotic and abiotic components, there are at least four general characteristics of global cycles that may constrain efforts at long-term element cycling research

- Variability across landscapes and between ecosystem types;
- Linkages between the cycles of different elements;
- Potential feedback of climate change on element cycling; and
- Potential nonlinear responses to perturbations.

A hierarchical approach with respect to the geographical scale of analysis is needed in order to contend with these characteristics. Scales ranging from local ecosystems,[1] and their specific processes, to the biosphere must be considered. Concepts, data, and models are strongest at the local ecosystem level, and impacts are often first perceived locally. The development of satisfactory methods to extrapolate results based on site-specific studies to larger spatial scales is a key issue for long-term ecological research.

Core data for understanding ecological processes are derived from intensive monitoring and experimental programs at representative field sites. Eventually, ecosystems that are representative of each element of the hierarchy must be included to arrive at a total picture. In choosing sites for long-term monitoring, emphasis needs to be placed on representing broad categories of ecosystems. At the ecosystem level, models can be sophisticated and explicitly incorporate fundamental system processes. Testing and verification of such models have often been more rigorous than of those that depend on the use of complex ecosystem component data. Translation of observed changes in variables that can be measured into changes in other variables that are difficult to measure, but which may be critical in understanding impacts at larger spatial scales, is an important application of accurate ecosystem models and their underlying data sets.

Linkages between element cycles and climate require increased attention to intensive site specific studies. Using such studies, researchers can identify basic mechanisms and measure them in such a way that they can be reliably handled in studies at larger spatial scales. Moreover, results based on work at specific sites cannot be extended easily to the global scale. Research is required to develop an understanding of variations that can be derived by analyzing large data sets. This research should lead to more general descriptions that are applicable to all important variables and parameters.

The natural distribution of ecosystem complexes is the basic level of organization suitable for translation across spatial scales. Explicit treatment of the geographic distribution of these complexes in data collection, analysis, and modeling then becomes an important element of a hierarchical approach in which data on local ecosystems are synthesized into useful models of entire landscapes, biomes, and the planet's biosphere. For example, the substantial prior investment in carbon cycle research is an indication of the level of effort required to reliably project future responses of global cycles to disturbance by human activities or of changes (such as climatic change or major volcanic activity) attributable to natural variations. The carbon cycle is but one biogeochemical cycle that exerts an impact on climate. The interactions of other key element cycles (for example, N, P, S, and O) must also be studied within the framework of a long-term research strategy.

Two major uncertainties exist in understanding past changes in the carbon cycle: the history of atmospheric CO_2 concentration prior to the beginning of accurate measurements in 1958; and, the history of changes in carbon storage in vegetation and soil. These two uncertainties should receive long-term research priority.

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[1] Ecologists generally consider the local ecosystem the lowest (geographical) level of generality for purposes of analysis. Thus, although environmental impact analysts would generally view the project, or site-specific level as that at which data and models are best developed and most accessible, that is a level not normally characterized in ecological analysis.

Our lack of knowledge about changes in atmospheric CO_2 concentration prior to 1958 shows the potential impact of inadequate or inappropriate monitoring of global environmental variables. The costs of attempting to reconstruct pre-measurement CO_2 records from proxy data such as CO_2 concentrations in air trapped in ice cores, or by modeling studies, have proven to be substantial. Work to reconstruct the history of carbon storage in the planet's terrestrial ecosystems is also proving extremely tedious. Satisfactory analysis of the impacts of land-use change on terrestrial carbon storage requires detailed knowledge of the ecological processes responsible for carbon cycling and the response of these processes to perturbations.

The general framework for long-term element cycling research incorporates two basic needs: world-scale monitoring and hierarchical approaches for synthesizing understanding of processes at the ecosystem level. Fulfillment of these needs can provide a means of translating this knowledge to larger spatial scales. Shortfalls in either aspect of the described framework can be expected to result in gaps in knowledge (or in the reliability of conclusions) that will limit applicability of research to policy development.

Toxins and Toxic Effects

Toxic materials are regulated not only to protect humans from poisoning but also to protect the human habitat, apart from man. The most important and valuable segment of the habitat is the biota, that is, other living organisms essential to maintaining the habitability of the planet. A program of toxin regulation that is effective in protecting the biosphere's organisms other than man will go a long way in protecting man as well. Programs focused solely on protecting man over the short term do not adequately protect other living organisms, and therefore cannot protect man in the longer term.

Toxic materials have now become global contaminants. The fact of the release of a toxin, whatever its purpose or source, constitutes a hazard. Pesticides, for instance, are commonly released into the air, where some fraction is dissipated, a part of which may move widely in the biosphere. Certain pesticides become hemispheric or even global contaminants that permeate the planet's oceans. Other toxins are wastes, deposited accidentally, by permit, or improperly into air and water, or onto land.

The system that the industrialized nations have developed for controlling toxins and wastes is imperfect. The scientific rationale for such regulation has been borrowed from the field of human and mammalian toxicology, but applied to the environment in general. It is based on three assumptions:

- There is a threshold for every toxin below which there are no effects warranting regulation. This threshold concept is applied to individuals, species, populations, and ecosystems;
- Given that there is a threshold for toxic effects, there must be an assimilative capacity for any toxin. Toxins are innocuous if concentrations remain low; and

- The primary objective of toxic substances control regulation is protection of people from toxic effects; protection of other organisms is either a secondary objective or is ignored.

A regulatory system based on the three assumptions noted above will work in a world in which the sum of human influences remains small in proportion to natural processes. It will generate a growing risk in a world in which toxin-generating human influences are continuously expanding. What regulatory approach will work? Reviewers of some of the recent ecological data suggest approaches that warrant consideration. For example, human interests can also be served well by a system of management that places a high priority on protection of the planet's biota. Thought must be given to how to reach an appropriate degree of isolation of harmful anthropogenic activities from the unmanaged environment. Long-term research is needed to assess the feasibility of such an approach. In particular, needed information includes

- Information on patterns of biotic impoverishment (at local, regional, and global scales);
- Long-term, detailed studies on the impacts of particular global toxins on the biological diversity of well-defined ecosystems that can be manipulated experimentally;
- Long-term research on man-dominated ecosystems (especially agricultural, urban, and industrialized areas) to learn how such systems can be made more benign, especially with respect to releases of widely circulating toxins; and
- Long-term research on how to better manage the earth's biota in ways that will allow both its use and its preservation.

Basic Ecological Knowledge for Environmental Assessment

Environmental assessments of Federal actions, initiated as a result of passage of the National Environmental Policy Act of 1969 (NEPA), are common elements of most (if not all) policy decisions. The NEPA process challenged ecologists to predict impacts on ecological systems from a wide array of stresses. To examine the role of ecological knowledge in environmental assessment, analysts consider case studies that illustrate how population biology, ecosystem studies, and regional analysis contribute to environmental assessment needs. Based on these analyses, it is possible to identify the need for and recommend support for long-term ecological research topics whose outputs would enable ecologists to improve the environmental assessment process.

The 17-year controversy surrounding electric power generation on the Hudson River provides a unique study of the usefulness and limitations of population-level studies in the environmental assessments. Biological resources potentially at risk because of entrainment and impingement of striped bass and other fish at power-generating facilities were highly valued, and measures to mitigate effects were very expensive. Central to resolution of the concerns was an understanding of the distribution and abundance of the Hudson River striped bass population. Massive field studies in the entire tidal Hudson were undertaken to quantitate adverse impacts. Compensatory mechanisms and density-dependent mortality regulating the population became a central issue. Mathematical models of the striped bass life cycle proliferated, but quantitative resolution of technical disputes was elusive. An out-of-court settlement was reached; it was focused on mitigation of existing impacts and long-term research. One lesson learned is that problems involving long-term dynamics of complex ecological systems cannot be solved through "crash" research efforts of a few years' duration.

Studies at the ecosystem level of organization have always been a major component of basic ecology. However, the present status of this subfield of biology is inadequate to enable analysts to perform ecosystem-level assessments. Assessment of toxic effects at the ecosystem level has been approached in laboratory model ecosystem studies (microcosms) or through mathematical modeling; in both of these approaches, analysts endeavor to reliably simulate ecosystem structure and functioning. Model ecosystem studies generally cannot be addressed directly to species of interest, and simulation models can be prohibitively unrealistic. The potential for the contribution of ecosystem ecology to impact assessment is great. Basic ecological studies of disturbed as well as pristine ecosystems are needed to develop ecosystem-level impact assessment methods.

The National Acid Precipitation Assessment Program (NAPAP) is an example of focused environmental research designed to address regional- and national-scale problems. The assessment framework is complex and emphasizes the need to develop linkages between emissions, transport/transformation, deposition, and effects at appropriate geographic and temporal scales. The NAPAP experience (degree of success) in producing a national assessment will define long-term research needs for national and regional assessments.

Basic ecological research required to support environmental impact assessment falls into three categories:

- o Anticipatory Research. Basic information is needed concerning the dynamics of important biotic resources that are vulnerable to anthropogenic disturbance, including exploited population such as striped bass and aesthetically valued populations such as bald eagles;
- o Participatory Research. Basic ecological research is needed to support ongoing assessments of major, long-term problems such as acid rain, the decline of the Chesapeake Bay, and photochemical oxidant effects on Southern California forests; and
- o Retrospective Research. Basic research is needed to determine the validity of assessment methods and models. Long-term studies are needed to distinguish effects from background variance and to track the processes of adaptation and recovery.

Environmental impact assessment practitioners, who will make use of this research, must make specific predictions about clearly defined endpoints so as to generate testable hypotheses. In addition, uncertainty must be explicitly addressed. Specific research efforts can be rank ordered on the basis of the relative uncertainty associated with each of the assessment components. Estimated uncertainties are also part of the set of hypotheses to be tested in validation studies. From validation studies, assessors can unearth areas of ignorance of which they have been previously unaware (the unknowns such as improper boundaries or unknown process linkages). Assessments with these characteristics have been termed "environmental risk analyses" because of their similarity to engineering and human health risk analyses. The development of methods for environmental risk analysis is only beginning and should itself be a subject for long-term research.

Mitigating Impacts From Complex Technological Systems

Anticipating and mitigating effects on natural resources, as well as on human resources, from the residuals of complex technologies requires well-defined, forward-looking research, rather than case-by-case reactive studies of problems that could have been avoided. Major questions remain, however, as to how to explore and guide the expanded ecological knowledge base needed to minimize unanticipated impacts from changes in technology.

The three subject areas in which expanded ecological knowledge is likely to be needed to mitigate impacts from emerging technologies are the following:

- Agriculture (forestry, range management, freshwater fisheries, and the intensive cultivation of cereals, fruits, and oil crops);
- Transportation (including waterborne, pipeline, air, and interurban corridor developments); and
- Urban systems, ranging from aggregates of small cities in otherwise rural areas to suburban complexes and developing megalopolitan corridors.

In agriculture, there has been a slowing down of the rate of increase in yields of major food crops. Wheat, sorghum, soybean, and potato yields in the United States have not increased at their historic rates since the late 1960s. Several factors have been suggested as contributing to slower rates of improvement in agricultural productivity. Agriculture is the chief user of land, water, and air resources, and all of these must be of a quality consistent with the high productivity and high quality expected of agricultural production. New technologies in urban or industrial regions need to facilitate stable production in the agricultural sector.

Transportation is already a complex technology with profound primary and secondary impacts on land (corridor impacts), water (due to runoff), and the atmosphere (due to emissions). As land transportation corridors change in the years ahead, as river, lake, and coastal shipping patterns change, and as air transport changes, new patterns of residual releases to air and water will emerge and new materials in these residuals will almost certainly be encountered. For the transportation sector, models are the most widely used means of describing trends in the complexity of present and future technologies. Models have been developed to facilitate planning and operation of almost all forms of transportation, and have been used frequently in land-use planning and resource impact analysis. Problems with transportation systems analysis and prediction of the impacts of related technologies stem largely from a lack of defined or consistent urban and regional environmental goals, as well as from a less than fully developed set of risk definitions.

Urban systems, together with their built-up suburbs, can be regarded as ecosystems importing food, water, fossil fuels, and raw materials, while exporting sewage, combustion products, and solid waste. Although ecosystem waste products exit from the city in highly modified forms, and ecosystem processes operate under highly stressed conditions, many of the principles governing material exchanges in normal ecosystems have been found to hold in the city. Human activities within urban systems cause increased production of organic materials as well as release of residuals to the air and water. All of these can operate locally to change the soil, hydrology, and climate, in turn influencing the productivity of both the managed (agricultural, park, and commercial forest) and the unmanaged natural ecosystems that surround the city.

The impacts of these technologies that may need mitigation in the future can be understood best by tracking changes in residuals from early technology. Future releases of residuals to the air, for instance, will depend primarily on three factors:

(1) Growth in energy requirements, particularly for electricity, industrial processes, and automobiles;

(2) The types of industrial or economic expansion taking place in urban areas and the energy form used to meet future demand (for example, the extent of nonfossil energy sources such as solar and hydropower); and

(3) The rates at which existing pollution sources (for example, both point and nonpoint sources) are replaced with newer sources more tightly controlled under the Clean Air Act.

Predicting the influence of each of these factors is difficult. We can make rough projections for the quantities of regulated pollutant emissions, assuming any of several plausible future courses in legislation, compliance, and enforcement. Much more difficult, however, and requiring intensive anticipatory research, are projections of the trends in the emissions of presently unregulated substances (polynuclear aromatic hydrocarbons, aldehydes, dioxins, and their possible transformation products) that are expected to increase with the introduction of new technologies in agriculture, transportation, and urban systems, including urban incineration of waste.

Residual releases from urban and agricultural systems to water environments should be viewed as a sequence from their origin in homes, industry, and on land, to a fate in the total urban or rural air and water system. Environmental impacts through disposal of residuals to water from urban and transportation technologies occur not only at the site of final disposition (sludge spreading, landfill, or incineration sites), but also at other stages in the waste treatment cycle.

Among the important "residuals" of agricultural systems are soil and its associated chemicals. Soil erosion is a serious national problem, compounded now by the high level of related pollutants carried with soil from agricultural systems to the nonagricultural environment. Animal wastes from feedlots and from other intensive animal production facilities also constitute important sources of residuals. Increasingly, these wastes may be put to good use, but their use or disposal may also engender new risks.

Almost any human activity produces some effect on surrounding resources--air, water, or the biota. Large-scale, complex technologies produce diverse impacts and great risk of consequences for heath, productivity, or other amenities crucial to our society. The essential questions here are: (1) What is a significant effect? (2) What is the certainty of the effect (as opposed to a natural background trend)? (3) If the effect is only a possibility (that is, a risk), at what probability level should the risk be judged as significant? and (4) Most fundamentally, are we developing the baseline information and ecological understanding to determine what constitutes a significant impact or risk?

The Nation already is making an immense investment in monitoring of air and water quality. Most of these measurements, however, focus on the effects of residuals on ambient values of receiving media (air, water, and soil), rather than on ultimate effects of pollutants on humans and other living organisms. Measurements of effects of complex technologies on natural resource systems (for example, the effects of acidic deposition) are exceptionally difficult, and will require intensive programmatic research, ideally with replication at numerous locations throughout the country.

In addition to the need for long-term measurements as a means of understanding or validating ecological assessment tools, and the need for all agencies who may use such data to contribute to their development, problems also exist with the reliability of, and access to, existing long-term monitoring of physical and biological systems. Most of the needs cited above rest with Federal agencies, whereas most of the reliability and access problems rest with state agencies. The impetus for improvement in data quality and data access arose from two parallel developments: first, the increasing importance of reliable data for determining the consequences of technological applications; and second, the unnecessary cost of having each investigator or decision-maker find, read, and appraise all original information relevant to a problem area or decision. Based on these examples,equal priority must be attached to the accessing of examples, equal priority must be attached to the accessing of existing data and to the development of new ecological data bases.

Habitat Diversity and Genetic Variability

In coming decades, the global diversity of ecosystems, species, and genotypes within species is likely to decline at a rate without precedent in the last 65 million years. Although highly industrialized nations are significant contributors to this decline, most of the loss will occur in less industrialized nations, where biological diversity, human population growth rates, and pressures for development are highest, but where infrastructure is least equipped to deal with this problem.

Direct effects of this loss will include sharp declines in quality of life, economic growth, and survivorship of large numbers of humans. These effects are expected to result from loss of aesthetic and psychological benefits, from loss of intellectual benefits, and from losses of ecosystem goods and services.

People, in fact, may have an innate psychological need to be surrounded by nonhuman life. Among other things, we depend on animals as surrogates for humans in many kinds of research. Wild plants, animals, and microorganisms serve as food, medicine, energy, and raw materials for humankind. The structure of, and interactions within ecosystems result in indispensable free services, including maintaining the chemical composition of the atmosphere, moderating the climate on at least local and regional levels, minimizing the effects of flood and drought, creating and enhancing the fertility of soils and preventing their erosion, providing food for free-ranging livestock and fish populations, pollinating crops, controlling pests and diseases, and degrading natural organic detritus and anthropogenic chemical pollutants. By driving and modulating biogeochemical cycles, the biota provide for the habitability of our planet.

Loss of genetic diversity within species diminishes their evolutionary capacity to withstand environmental change. Extinctions of populations are even more frequent than extinctions of species.

Loss of some species can cause marked changes in community structure and ecosystem function, and possibly, cascading extinctions among dependent species. Historical examples are the extinction of dodos and sea otters (throughout part of their range). Nonetheless, some ecosystem measures, such as primary productivity, may not change substantially when some species are eliminated, because some ecological processes are performed by multispecies "guilds" that provide varying degrees of functional redundancy. Losses of entire guilds--for example deforestation--cause far greater physicochemical and biological changes to the ecosystem than losses of single species. Loss of ecosystem diversity eliminates both species endemic within those ecosystems and animal species that must migrate among particular ecosystems.

Long-term research on biological diversity is needed because

- Processes underlying health and decline of biological diversity are complex;
- Many processes unfold slowly, over periods of decades or more; and
- Rare natural events may be far more important in determining community composition, structure, and ecosystem functioning than usual conditions.

Indicators of Change in Natural and Human-Impacted Ecosystems

Although ecologists measure numerous variables as indicators of change, many measurements are based on inadequately tested assumptions, and most have relatively poor precision with limited potential for improvement. The lack of precision and occasional controversy over the validity of an approach have lessened the effectiveness of ecological inputs to decisionmaking. The vast majority of decisions concerning the release of chemicals are based on estimated risk to human health, rather than on ecological concerns. Even in those situations when ecological aspects cannot be ignored, a projected cause-effect relationship has often been challenged with arguments that other causes were responsible or that the change was part of natural variation.

Data exist that could be used to effectively test the assumptions, accuracy, and precision of measures of ecological change. Some of these data exist in post-impact monitoring of projects for which environmental baseline data and predicted effects were documented in environmental impact statements (EISs). Other data exist in academic or scientific agency studies. Currently there are no organized plans to accumulate and interpret the data, to provide well-documented case histories of cause-effect relationships, or to test various measures of changes. These goals could be accomplished through appropriately organized and funded efforts; the harvesting of these efforts, especially of the EIS work, should be cost effective.

There are many proposed indicators of change, but few have any measure of precision, and even fewer have a track record of having been useful to a variety of scientists in different environments. Many of the indicators of change are based on ecological assumptions that have not been critically tested. Because there is more prestige in proposing new indices than in testing existing ones, large numbers of potential indicators--each with a narrow data base and a lack of confidence--tend to accumulate within the discipline of environmental impact analysis. There is uncertainty about which variables should be included in environmental monitoring.

Many of the ecological indicators of change are based on single species data, either of individual health or population characteristics. These indicators of change include yields of economically important species, changes in abundance or reproductive success of obvious species (for example, birds, and turtles), growth rates or estimates of scope for growth, bioaccumulation of xenobiotic chemicals or metals, tumors or cellular abnormalities, enzyme levels (that is, excessive or depleted), energy state, and behavior.

All of the indicators of change are prone to local and annual variations. One serious shortcoming of bioaccumulation data is the lack of appropriate information from which to infer biological effects of the accumulated toxicant; unfortunately, most toxicity data are correlated with the exposure concentration, not internal concentration. Specific chemical causes have not been associated with cases of cellular or enzymatic abnormalities.

Indicators of change based on community structure include changes in species dominance, abundances of indicator species, similarities or difference indices to a reference (control) community, species diversity or evenness, vulnerability to invasion by exotic species, abundance of biomass or chlorophyll (especially for eutrophication), and patterns shown by remote sensing.

Most research has concentrated on species diversity because of its presumed relationship to stability of ecosystems, their properties, or their processes; this relationship is now under question. In many cases, the existence of stress is likely to eliminate sensitive species and increase the abundance of resistant species. However, under certain conditions, stress may also increase diversity. In practice it has not been possible to cite a specific value above which an ecological community might be considered as healthy, and below which its health is compromised.

Indicators based on community function have been hypothesized, and many have been demonstrated in specific cases; however, the class of indices has not been systematically tested to see if the generalizations are valid. Many of the indicators such as respiration, heat output, production/respiration or respiration/biomass ratios, nutrient retention or cycling, and physicochemical changes are based on the general assumption that natural succession causes predictable changes in ecosystems and that disturbance tends to force ecosystems to less mature states.

New research should be focused on community structure and function indicators. It is critical that known effects of stress be distinguished from, or related to, natural variations associated with climate or other cycles. Much of the new research should be experimental, such that replicated pairs of control and treated communities can be compared. These studies should involve natural communities, enclosures, mesocosms, microcosms, or any unit that is appropriate to the questions being asked. Single impact-control paired sites, or use of gradients associated with a stress, are the methodologies of choice in some cases, especially when long-term studies have been initiated. Studies must be conducted over a long enough period to assure that seasonal and annual variations are included.

Mitigating the Impacts of Current Technologies

Despite great improvements in pollution control and management, some technologies still pose potential threats to the environment. These technologies include industrial manufacturing, resource development, energy production, and agriculture.

Placement of sludges in landfills and soil application of liquids or sludges are the major sources of discharge to the terrestrial environment. If not managed properly, both may result in soil and groundwater contamination. Because a great deal of intermedia transport occurs, it is necessary to develop a multimedia focus for environmental research and regulation. This necessitates long-term research to enable us to determine impacts on all segments of the ecosystem.

Land application techniques are in need of such long-term research. Included in this category are the techniques of irrigation, rapid infiltration, overland flow, land disposal of sludge, and wetlands application of wastewater. The number of such techniques in use is steadily increasing, and post-construction performance evaluations as well as long-term follow-up studies are necessary to assess the potential hazard of long-term usage. In particular, additional information on pathogen survival and transport and on heavy metals build-up is desirable. Additional studies on the use of forest land for irrigation systems, especially under freezing conditions, are needed. Studies of process kinetics of overland flow systems are needed to aid in the design of such systems. The fate, transport, and transformation of contaminants in the soil need to be investigated. This information is necessary not only for prevention of impacts, but also for cleanup of contaminated aquifers. Studies on biodegradation, adsorption, and hydraulic transport are necessary.

Extensive research is needed on decontamination of groundwater. In particular, the fate of organic pollutants in an aquifer may depend upon the type of microorganisms present, and their ability to transform or degrade the pollutants. Information is needed on how these organisms interact and grow to determine their potential for aquifer decontamination. Studies are necessary to determine the extent and effect of nonpoint source pollution at a national level. To ensure adequate control of such pollution, followup studies to determine the effects of the controls employed need to be done.

Research on dechlorination techniques has been stimulated by findings of recent studies that chlorine combines with humic substances to produce significant amounts of potentially hazardous halocarbons. Researchers now believe that sulfur compounds may be best for dechlorination, but research on process kinetics is still necessary to determine proper operating conditions. Resulting effects of the dechlorination agents on the aquatic environment also need to be determined.

Research is needed on the fate of sediment contaminants. Factors that can affect the persistence and transport of toxic chemicals on sediments, and the release of toxic chemicals to the water, are not well understood. It has been suggested that such releases are an important source of exposure for aquatic organisms.

The long-range transport of chemicals in the atmosphere is a problem of considerable importance. Methods to monitor and control such pollutants must be developed. Of particular concern are the products of incomplete combustion that may be released during the incineration of hazardous wastes. Also of concern is the release of volatile compounds from industrial waste landfills.

The problem of acid deposition is still a major one. Studies on the atmospheric transport of sulfur dioxide and nitrogen oxides are needed. Increased research efforts should be focused on the importance of nitrogen oxides and other air emissions on acid deposition. Increased research will be needed to determine the mechanisms by which waterways may become acidified by acid deposition. Also, not enough is known about the effects of acid deposition to forests and croplands from acid deposition.

Insufficient attention has been given to developing methods of waste recycling and reuse, emphasizing more efficient and effective techniques than are now commonly used. In addition, not enough is yet understood about the problem of hazard evaluation and risk assessment. In particular, there has not yet been developed a comprehensive chemical monitoring program that enables analysts to assess long-term trends.

We believe that future environmental research on mitigating the environmental impacts of current technologies should have a multimedia focus, because extensive intermedia transport of pollutants can occur.

Anticipating Potential Impacts of Emerging Technologies

Genetic engineering is a specific case that illustrates some of the issues that arise in defining approaches and research needs for predicting potential environmental impacts of emerging technologies.

Environmental problems have often arisen in the past following the introduction of major new technologies. There are no compelling a priori reasons to believe that genetic engineering is any different in this regard. A number of hypotheses have been advanced in support of the view that the risk of genetic engineering is negligible, but these arguments, though having merit, are far from definitive. Of particular concern is the fact that the growth of this new technology will likely involve the application of gene-transfer techniques to an array of organisms, and that the consequences of this application cannot be predicted. Moreover, although major long-term ecological disturbances are not common in nature, they do take place, either when the natural community is upset, as commonly occurs in agriculture, or when a species is newly introduced into an environment. Although some of the upsets following the introduction of exotic species have been catastrophic, few well-documented explanations exist to account for the success of some introduced species and the failure of others.

The potential environmental consequences and risks of genetic engineering have attracted considerable attention, but they remain virtually unstudied. It is generally believed that the probability of a significant environmental change or upset is small, but no consensus exists on how small is small. A substantive base of scientific information and meaningful predictive tests is, therefore, required. This will allow development of a predictive capacity, from suitable testing protocols, to evaluate potential environmental impacts. Information is particularly needed on the following potential hazards:

- The likelihood that an organism will be deliberately or inadvertently introduced into a natural or human-altered environment;
- The probability that it will survive in that environment;
- The probability that it will multiply at that site;
- The likelihood that genetic information will be transferred from the released organism to other species and that the latter will survive and multiply;
- The probability that the organism containing genetic information of ecological importance will be dispersed to make contact with species that it can injure; and
- The possibility that some deleterious alteration will take place.

Research designed to detect released organisms is of great importance. Particularly among microorganisms, attention has been given to the development of such methods, but the techniques have rarely been applied to genetically engineered microbes. Information is needed on the effectiveness of containment procedures, routes of release from the laboratory or fermentation facility, the probability of release via each route, and on factors affecting the use of organisms debilitated to prevent their establishment in natural environments. Information is also needed on the potential for survival of organisms produced through genetic engineering, the environmental conditions allowing for the survival of organisms that usually do not persist, and the traits of species able or unable to endure in natural environments.

Scientists now believe that gene exchange takes place between microorganisms. This belief needs to be verified, and the factors governing the exchange need to be defined. To this end, the types of genetic exchange that take place, the organisms and conditions most likely to be involved, and the outcome of these transfers of genes need to be determined.

It is generally not possible to predict accurately whether a particular introduced organism will, or will not, be disseminated to a site where it may have an impact; hence, research is needed to establish the types of organisms that are susceptible to dispersal, the mechanisms of this dispersal, environmental conditions that favor or are detrimental to dispersal, and morphological and physiological characteristics of the organisms that make them more or less susceptible to dispersal.

Of critical importance is the potential of the genetically engineered organisms to affect natural populations and communities. Inasmuch as information is limited on the mechanisms by which harm is done to natural populations and communities, exploratory research on species interactions is needed. In performing such research, scientists should consider the basis for species interactions and whether experiments can be devised to predict the possible harm done by genetically altered organisms to established natural communities. Taxonomic categorizations of organisms (for example, pathogens, parasites, or predators) that affect ecologically important species interactions need to be established. Attention needs to be given to the design of suitable and low-cost model ecosystems to predict how genetically altered organisms might affect ecosystem structure and function. The utility of these model ecosystems for field predictions, however, must be validated. Research is also needed to establish the ecosystem processes particularly susceptible to disruption by pathogens, parasites, and predators.

A credible testing program to be used both by industry and by regulatory agencies cannot be devised until some of these information gaps are filled. Although much can be learned from the existing scientific literature, that literature is still too sparse and is often devoted to issues not relevant to species likely to be employed in genetic engineering. In addition, the extent of financial support for research in this area is extremely limited, and no major increase in funding has been publicly announced.

RECOMMENDATIONS

We have adopted recommendations within five categories of research focused on the structure and functioning of ecological systems. In addition, we have added a sixth recommendation for shoring up the Nation's institutional resources and professional training programs. We emphasize that the conduct of research contained in our recommendations will require substantial increase in the amount, quality, and diversity and continuity of support for long-term environmental research. Specific recommendations by research category are as follows:

Fundamental Studies of the Ecological Dimensions of Biospheric and Global Processes

- Illuminate the role of biological linkages and processes in specific biogeochemical cycles (for example, C, N, P, S, and O); and
- Characterize the interactions among these biogeochemical cycles and the relations between these and climate.

Applied Cause/Effect and Dose/Response Studies of the Impacts of Global Pollutants on the Ecological Dimensions of Biospheric and Global Processes

- Search for biological interactions and ecosystem processes that are most sensitive to specific present, past, and anticipated global pollutants and environmental stresses; and

- Characterize the interactions among global pollutants in producing impacts on the ecological dimensions of biospheric and global processes.

Fundamental Studies of Ecosystem Structure and Processes

- Establish and sustain a national network of representative ecosystem sites at which long-term ecological studies can be pursued. This network should include both relatively natural and intensively managed (that is, agricultural, fishery, and urban) ecosystem study areas;

- Sustain long-term biological inventories and records of baseline ecosystem structures and processes;

- Identify those ecological dimensions and processes that are related to the sustainability of ecosystem resources and amenities, especially conservation of biological diversity. Initiate a new, comprehensive program (probably within the National Science Foundation) in conservation biology, including conservation biogeography, ecology, genetics, and behavior. It is currently impossible to determine priorities for conserving biological diversity because we have major gaps in our knowledge of geographic patterns of diversity. Substantially increased funding for systematics is also needed. Because most of the losses are occurring in the tropics, basic studies in tropical ecology are needed, particularly in freshwaters, nearshore marine ecosystems and lowland forests. One component of this research strengthening should be the extension of the National Science Foundation's Long Term Ecological Research program to include terrestrial, freshwater, and marine sites in the Neotropics;

- Establish a research program to study the effect of global climatic change on isolated habitat "islands." Without accounting for the eventuality of climate change, the strategy of conserving biological diversity in parks and other reserves is unlikely to succeed; and

- Identify processes that link different ecosystem types (for example, suburban-urban, agricultural-fisheries, industrial-agricultural systems).

Applied Cause/Effect and Dose/Response Studies of Technological Impacts on Ecosystem Structure and Processes

- Initiate model ecosystem and field experimental studies of the impact of specific technology stresses on ecosystem structures and processes;

- Search for early signals of ecological impacts and study their reliability for environmental forecasting;

- Search for attributes of ecosystems that offer opportunities for mitigation of environmental impacts;
- Search for safe means of simulating possible environmental impacts of emerging technologies (for example, genetically engineered new organisms, synfuels, and communication technologies waste streams and resource demands);
- Study interactions of various technological impacts on ecosystem processes and structures;
- Conduct research on how man-dominated ecosystems such as cities and industries can be moved towards closure, especially with respect to toxins; and
- Identify representative sites at which significant man-made or natural changes have already had an impact on or are about to have an impact on ecosystems. Document changes that have occurred based on published or unpublished pre-disturbance studies and on reconstructions from fossil and paleobiogeochemical studies. Specifically search for ecological changes that operate on very different time scales.

Studies of the Tools and Methods of Ecological Research, Risk Analysis and Management, and Long-Term Environmental Management

- Evaluate existing physical, chemical, and biological monitoring programs and records with the objective of identifying and stimulating R&D for improving their quality and cost-effectiveness as well as their utility in predicting ecological impacts and efficacy of mitigative measures;
- Evaluate the major national and international sources of long-term ecological and environmental management R&D with the objective of improving interaction among government, university and industry research groups; identifying the most cost-effective ways of strengthening long-term ecological research on high-priority national and international environmental challenges; and assessing the supply of trained professionals at work and in the training pipelines and identifying cost-effective means for ensuring a continued adequate supply; and
- Search for and evaluate strategies for environmental and ecological impact mitigation with the intent of facilitating their adoption when cost effective.

Institutional and Professional Training Needs

We feel that the long-term environmental research needed in order to address the problems raised above is not adequately reflected within the existing funding and management structures. Extramural environmental research sponsored by the U.S. Environmental Protection Agency (EPA), as well as EPA's Centers of Excellence Programs, are judged as steps in the right direction although both programs are inadequate to meet the research needs. Long-term research cannot be managed and funded piece-meal and in a temporarily unpredictable fashion. We discussed extensively the possibility of creating a National Center or Institute for Long-Term Environmental Research. The

National Center for Atmospheric Research was suggested as a possible model for the establishment of such a Center. At the same time, some of our Panelists feel that such a Center should be a step removed from the government and managed like a national laboratory by a consortium of universities. The inability of universities to manage long-term interdisciplinary research was mentioned as a deterrent to the success of basic environmental sciences and an argument in favor of a National Center for Environmental Sciences.

We also discussed the possibility of involving the private sector in funding long-term environmental research. The positive example of the Electric Power Research Institute, which has successfully managed a number of long-term multidisciplinary programs, was mentioned as a model for such involvement. Panelists feel that a general evolution from adversarial to collaborative relationships has been taking place between industry and government on environmental issues; this needs to be encouraged and used in the long-term development of environmental sciences.

The necessity of professional training in the field of environmental sciences and engineering was stressed by a number of Panelists. The establishment of training grants modeled after the practice of the National Institutes of Health was proposed. Such grants are needed to foster interdisciplinary programs in the leading universities of the nation. They should serve as a stimulus for overcoming traditional departmental structures that tend to be extremely stable in spite of all the efforts over the past decade.

APPENDIX V

Summary Report
of the
Expert Panel Meeting
on
Monitoring, Assessment, and Environmental Management

INTRODUCTION

The meeting on Monitoring, Assessment, and Environmental Management was included in the series of expert panle meetings in recognition of the fact that protection of public health and management of environmental quality can be assured only through the use of reliable environmental data and analyses. The topic areas that served as foci for background papers for and discussion at the meeting were

- o Data Generation, Collection, Analysis, and Interpretation;
- o Health Risk Assessment and Environmental Impact Assessment Techniques;
- o Modeling and Forecasting Techniques; and
- o Environmental Management Approaches.

THE CONTEXT

It is important from the outset to agree on the meaning and boundaries of our subject. Long-term environmental research and development (R&D) is taken to refer to a time period of approximately 3 to 15 years from the present, but even within that period it can be given several meanings: for instance, research whose outputs can be used in anticipating future environmental problems, research that requires multiyear time series data collection (such as prospective epidemiological and ecological studies), or "basic" research undertaken to illuminate fundamental properties of human and ecological systems that determine health and environmental effects.

A strong consensus emerged among Panelists to focus on future needs that are at least identifiable today, and not to attempt to identify wholly new concerns by speculation alone. In addition, the Panel decided not to limit its attention only to environmental concerns clearly within the authority of existing regulatory statutes. Because of the Panel's own mix of expertise, it may have unavoidably omitted some topics that other scientists may view as equally important as the ones considered; many of the examples cited, for instance, reflect the greater familiarity of the Panelists with pollution and toxic substances issues, rather than with environmental health, soil erosion and farmland protection, fishery and wildlife habitats, wetlands, and other topics on which long-term environmental R&D may be equally important.

In identifying long-term environmental R&D needs, a useful first step is to distinguish between research and monitoring: that is, between studies that attempt to improve our understanding of how environmental systems work, and studies that provide data on the status of those systems. Each is essential to the other in the sense that basic understanding must guide the choice of what parameters to monitor, and monitoring may in turn provide data from which postulates and theories are derived and assessed. The issue of reliability in the interpretation of data from research and monitoring studies, especially in the many situations of high uncertainty is an important one.

Research

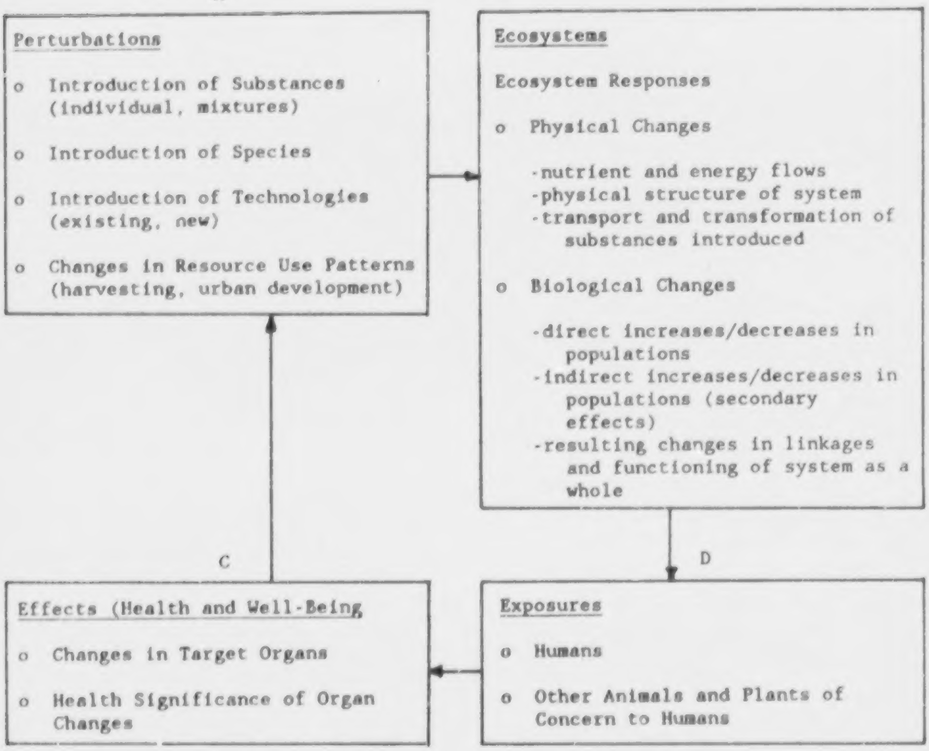
Figure 1 below is a simple conceptual model of how human actions may cause impacts on environmental quality and human health. The introduction of some human perturbation causes changes in the dynamics of an ecological system, these changes affect the exposure of humans and other living organisms, and such exposures in turn cause changes in those organisms that may have significance for their health and well-being. Human responses to these effects may also introduce additional perturbations that further affect the process.

Each of the four boxes, although greatly oversimplified, represents a cluster of questions that require answers from environmental research in order to permit sound management decisions. To understand the health effects of a toxic pollutant on humans, for instance, one must understand how much of it gets into the environment in the first place, how it is transferred within the ecosystem, to how much of it people are actually exposed (and by what pathways), and the acute and long-term effects of the biologically effective dose both on specific organs and on their overall health and well-being.

Typically, perturbations consist of complex mixtures of substances or impacts and equally complex patterns of human activities that influence exposure. Examples would include hazardous waste dumps and related groundwater problems. The dynamics of ecosystems are constantly affected by both manmade and natural perturbations; these ecosystems may transform substances into forms that are either more or less toxic.

Exposures occur via multiple pathways, and toxic pollutants enter humans via ingestion, inhalation, or contact. People are often exposed to complex mixtures of substances whose net effect may be synergistic, additive, or antagonistic, in multiple environments (at home or at work), and in amounts varying from single acute to chronic low doses.

Figure 1. Environmental Changes and Their Consequences


A
B
Perturbations
o Introduction of Substances (individual, mixtures)
o Introduction of Species
o Introduction of Technologies (existing, new)
o Changes in Resource Use Patterns (harvesting, urban development)
Ecosystems
Ecosystem Responses
o Physical Changes
-nutrient and energy flows
-physical structure of system
-transport and transformation of substances introduced
o Biological Changes
-direct increases/decreases in populations
-indirect increases/decreases in populations (secondary effects)
-resulting changes in linkages and functioning of system as a whole
C
D
Effects (Health and Well-Being
o Changes in Target Organs
o Health Significance of Organ Changes
Exposures
o Humans
o Other Animals and Plants of Concern to Humans

The effects of such exposure in turn may vary both by species and among individuals in how much of the toxic pollutant actually reaches target organs in the individual, how the pollutant changes the functioning of those organs, and how those changes in turn affect overall health.

Each of these aspects of environmental change gives rise to long-term research needs. In addition, there is a need for research on the linkages among them, especially between ecological systems and on exposures and health effects.

Ecosystems Research: We know relatively little about the functioning and maintenance of ecosystems and, indeed, it is important to address the basic question of what information we need to collect to determine if an ecosystem has been seriously disrupted. Major information needs related to this subject include the identification of critical and sensitive components of ecosystems, generalizations among ecosystems and types of stress, determinations of mechanisms of adaptation and/or damage, and valid methods for monitoring of normal ecosystem fluctuations.

Exposures: Much of the research on human exposure to environmental pollutants has been based more on modeling assumptions than on direct measurement, and has been fragmented among the various regulatory agencies and programs responsible for ambient environmental quality (and within that, air, water, and other programs), occupational health, food, and consumer products. Relatively little information exists on patterns of total exposure of human populations even to common individual substances, let alone to mixtures or interactive substances, despite the fact that assumptions about such exposures and biological dose are a key link in the chain between environmental pollution and human health effects.

It is clear that multiple exposures to multiple chemicals are the rule , not the exception, and it is important to determine total environmental exposure and total uptake by a wide variety of techniques in combination. The use of advanced detection techniques such as biological markers of exposure and animal and mathematical and models, is therefore a major research need.

Health Effects: How do exposures actually affect human hosts and their disease burdens? Much research so far has been focused on cancer and mutagenicity as endpoints, and on epidemiology and animal toxicology as major sources of evidence of health effects. The long-term effects of substances on the neurobehavioral system, on the reproductive system, and on the immune system remain largely unknown. The same is true of the contributions of pollutants to other chronic diseases such as those of the liver, kidney, heart, blood, and musculoskeletal system.

For the short term, substance-by-substance studies of cancer toxicology continue to be a valuable and necessary starting point. For the long term, however, greater emphasis is needed on a broader range of possible effects: on the basic mechanisms by which substances enter, interact with, and change the human body; and on the health significance of these changes.

Future Perturbations: Will patterns of human perturbations of the environment be substantially the same over the next 15 years, or will important changes occur that should affect research priorities? A credible long-term research agenda must be so designed such that researchers can take account both of trends and events that are now visible (either agreed upon or the subject of important controversy) and of long-term consequences that might be serious.

Monitoring

Good environmental research, monitoring, and management are iterative and interdependent. Research yields hypotheses about how environmental systems work; the outputs of monitoring are data about the status of those systems that permit both testing of those hypotheses and management responses. Monitoring thus ooought to be designed to serve as an essential complement to research, and must be closely linked to it, yet it raises such additional and difficult questions of long-term priorities as the following:

Purposes: No monitoring system can be designed to serve all purposes equally well, and most existing monitoring systems were designed to facilitate enforcement of existing pollution control regulations rather than to track basic ecological variables or to anticipate new problems. Few substances are monitored at all in the environment or in humans, and even fewer biological variables are systematically observed. What purpose(s) should guide the development of each monitoring system, and what compromises can and cannot be made to incorporate additional purposes without loss of scientific usefulness?

Design and Quality Control: What variables are appropriate indicators for the evaluation of monitoring strategies? What sensing elements, instruments, locations, frequencies of observation, data transmission, and analytical protocols will provide valid and useful measurements of environmental change? What analogous health indicators and tests are appropriate? How can data series already gathered for one purpose ("passive data sets") be used for other purposes and inferences?

Cost-Effectiveness and Continuity: Long-term monitoring is expensive and often little used; in addition, it frequently competes with research for the funds that support both activities. What biological and ecological variables are worth long-term monitoring, and what long-term research purposes do they serve? How can quality control and usefulness of the outputs be assured? What are the advantages of the continuity provided by long-term data sets, and how should these be weighed both against other data needs and against the benefits of altering measurement methods so as to incorporate more recent scientific advances?

Long-term monitoring programs may be an integral element of environmental R&D needs, if designed to provide valid and useful data to meet the most important R&D needs. It is thus important to reassess current efforts, to carry out quality control studies, to implement consistent time-series data on additional variables, and to create better linkages among monitoring programs.

Quality Control: The validity as well as the usefulness of some large environmental data systems should be periodically examined. It may be important to question the basic design of the systems, such as the locations of monitoring stations for particular variables, the range of variables measured, and the frequencies and time periods over which they are recorded. Other questions pertain to the quality of operation of the system, such as the training and reliability of the personnel who record the measurements and analyze the samples; still others concern the inferences drawn from the data, as, for instance, attempting to estimate ozone damage to crops when most ozone monitoring stations are in urban areas. Comparable problems of validity and quality arise in health exposure modeling.

Additional Considerations: Certain variables are so basic to a broad range of fundamental questions in environmental research that there would be broad scientific consensus on the need to monitor them on a long-term basis. Among the most obvious are data on climatic conditions such as rainfall and atmospheric temperature; on marine and estuarine conditions such as tidal fluctuations; and on such fundamental indicators of human health as mortality rates.

For many other similarly important indicators of environmental quality, however, we now have little or no monitoring data and often not even baselines against which to measure current conditions. Research is most often limited to short-term experiments that may or may not adequately reflect real systematic responses to stressors under field conditions, and models cannot be calibrated.

Interpretation of Contested Data Sets: A central problem in the application of environmental data to environmental management is the presence of uncertainties and conflicts over interpretation. Some of these conflicts may be rooted in legitimate differences of scientific opinion as to particular assumptions (for instance, the use of cell culture or choice of animal extrapolation models to predict human toxicology). It is important to be explicit regarding these assumptions.

Health Risk Assessment and Environmental Impact Assessment Techniques

Risk and impact assessments refer to two forms of applied analyses introduced into environmental management over the past 14 years, each intended to assure that managers have adequate estimates of the possible consequences of their actions to make well-reasoned decisions. A health risk assessment normally applies to a regulatory decision concerning the release of a particular substance into the environment, and involves the review and analysis of relevant scientific information about the substance's possible hazards and about the extent of likely public exposure to it. It is also sometimes applied to alterations of the environment, such as modifications of streams and wetlands.

An environmental impact assessment normally applies to any Federal action that may significantly affect human or environmental quality; it is most often prepared for actions by which Federal agencies undertake, permit, or support construction projects, and involves the inventory of environmental baseline conditions and the prediction of impacts on those conditions that would be likely to result from the proposed action or its alternatives, as well as likely measures to mitigate those impacts.

Both types of assessment are attempts to estimate possible consequences of future actions based upon available scientific information, in order to improve environmental management decisions, and both in practice usually require going beyond scientific estimates into the comparative evaluation and "balancing" of risks and benefits by the decisionmaker.

Health Risk Assessment: In concept, the rationale for health risk assessment is incontrovertibly simple. So long as government is expected to control some risks and can never have the knowledge or the resources to control all, some process of risk assessment is inevitable: the nature of environmental and health decisions implies it. The requirement of formalized and quantitative risk assessment (QRA) is intended to be an instrument of both scientific rigor and democratic accountability, ensuring that the inevitable process of assessing risk is documented in a reviewable public record and supported insofar as possible by scientific data and methods. A QRA for human health effects, for instance, in principle includes four primary elements:

- Hazard identification (the causal relationship between substance and effects);
- Dose-response assessment (the relationship between dose and incidence in humans);

- o Exposure assessment (the actual human exposures expected under plausible conditions); and
- o Risk characterization (the estimated incidence of adverse effect in a given population).

These elements of the risk assessment are the basis for management decisions balancing the social costs and benefits of reducing or prohibiting the risks.

QRA is in fact only one of several risk assessment approaches presently available, however. For instance, EPA now uses risk assessments in six of its major programs, including hazardous waste cleanup, and toxic substances; it conducts QRAs for carcinogenic effects, though often not for other types of health or ecological risks.

Scientific uncertainties often plague many of the assumptions of QRAs, including the extrapolations from particular laboratory animals as analogs to humans, from high to low doses, from small samples and single studies to large populations, from qualitative bioassays to QRA estimates, and even from intensively exposed or well-studied human groups to other populations. These uncertainties may be compounded by adding or multiplying them together in a QRA, a process which can lead to risk estimates that differ by up to 6 orders of magnitude. As a result, QRAs represent an imperfect analysis and cannot always be used; some experts prefer traditional professional judgment to a QRA procedure that depends on quantitative estimation.

There is substantial agreement among experts on the Panel and elsewhere, therefore, that risk assessment can benefit from long-term research.

Scientific Basis. The central scientific problem in risk assessments is not so much the risk assessment procedure itself but the absence of good understanding of the underlying systems and processes, as discussed in the earlier section on research. Too little is now known, for instance, about the basic pharmacodynamic and ecological mechanisms of toxic effects, about virtually any health (other than cancer) or ecological effects, about actual exposure patterns, and about the potentials of short-term biological screening to provide early predictions of effects. The primary long-term research needs therefore are also largely identical to those discussed earlier. The choice of assumptions, models, and significance criteria under conditions of genuine uncertainty may reflect differences among scientific perspectives.

Environmental Impact Assessment: Environmental impact assessment (EIA) has been well established as an analytical procedure for over 14 years; since 1978 it has been refined and codified in Federal regulations by the Council on Environmental Quality, including explicit procedures for establishing the scope of analysis in consultation with all interested parties. Although less controversial now than in their earlier years, however, EIA studies are still limited in their quality by certain fundamental gaps in long-term research. As QRAs would benefit from increased knowledge of health effects mechanisms, so EIAs could benefit from increased understanding of ecosystem dynamics. Most EIAs are focused on fish and wildlife, plant conservation, and endangered species, rather than on small species--such as microorganisms and pollinators--that may perform crucial ecological roles.

Modeling and Forecasting Techniques

Scientific models are commonly defined as quantitative expressions of hypotheses, ideas, concepts, or observations that permit pertinent information and data to be assembled, processed, and evaluated. In this context, environmental modeling includes a large number of instruments of several different types: data collection guides, assessment frameworks, evaluation techniques, and tools for predicting environmental effects over a wide range of situations and conditions. Over the past five years, an increasing number of Federal agencies and programs have turned to simulation and optimization models, as well as other kinds, as aids to environmental management. Some of these models have been developed within the agencies; most, however, depend heavily on modeling expertise in universities, national laboratories, and consulting firms.

At their best, models may improve understanding of ecosystems, reveal logical inconsistencies and gaps in knowledge, and focus and communicate information in a clear and concise fashion. They remain one of the few quantitative tools available for exploring the hypothesized effects of human perturbations on natural systems. Some models have only a few or a single user; and the complexity of some models reduces their usefulness as tools for understanding or prediction. A large proportion of models lack adequate documentation and verification. Models also reflect, of course, the quality of the assumptions and data that go into them.

Environmental Management Approaches

Environmental management depends on data and monitoring, assessment, and modeling, but also it is a subject of long-term R&D needs in its own right, involving two subject areas. The first of these is habitat management, the purposeful manipulation of ecological conditions. The second is the management of environmental programs, including the uses of research, monitoring, assessment, modeling, and the design and evaluation of alternative regulations, incentives, and other types of government interventions.

Our environment is sustained by a basic structure composed of biota, land, water, air, and energy resources, which interact in a dynamic manner. In the past scientists were seldom asked about the full consequences of human intervention. There is a need for more holistic, interdisciplinary approaches to the biophysical environment.

Federal environmental programs are conducted under a series of several dozen laws, covering different media, enacted at different times, and administered by different offices and programs. Long-term research is needed to improve the scientific basis for integrating these environmental programs into a single environmental policy.

RECOMMENDATIONS

The Panel believes that its discussions and recommendations must be focused on two critical components in the use of data for environmental management purposes: research and monitoring.

Research

For the research component, the Panel recommends attention to the following types of studies:

The Dynamics of Stressed Ecosystems: We recommend that attention be given to the collection of better long-term information on (1) the changes that occur in ecosystems in response to manmade stresses, with the goal of understanding what changes occur in response to what elements of the stress, and by what processes; (2) whether such changes are transient, adaptive, or pathological; (3) how such changes are avoided, amplified or mitigated by natural (that is, nonhuman) sources of fluctuation and stress in the system; and (4) what actions to provide additional avoidance or mitigation might be practical and effective. Stresses in this context refer not only to discharges of chemical pollutants, but to the full range of human development and use patterns, with priorities set according to which stresses appear most significant. This research is especially needed for ecosystem types in which changes are irreversibly damaging, and for those that have great value to human populations and are under great pressure from manmade stresses, such as wetlands and estuaries.

Ecologically Significant Endpoints: We recommend that as the dynamics of stressed ecosystems are better understood, studies are undertaken to identify specific changes in measurable system process parameters and species populations that define thresholds of ecological significance--for instance, those that foreshadow qualitative and perhaps irreversible changes in the functioning of the system. These parameters and organisms should therefore become potential endpoints for regulatory attention. (Some parameters may not have any thresholds). Simple physical and chemical variables (such as pH and dissolved oxygen) are already used as crude endpoints for some purposes; additional endpoints may be needed for other physical and chemical variables (such as groundwater quantity and quality, and nutrients and toxins) and for biological variables (such as biocides and species composition).

Ecological Markers and Sentinel Events: We recommend that research be undertaken to identify early indicators of potential ecological change, such as especially sensitive species or interactions between species whose condition if monitored provides a precursor or sentinel change to warn of impending adverse effects on the system. Mussels have already been identified for this purpose in some marine systems, and ceriodaphnia, fathead minnows, and algal changes in streams; we recommend that research be done on analogous markers both for other types of ecosystems and for additional types of stresses. Bumblebees, earthworms, and fungi have been suggested as indicators of change for terrestrial systems, for instance, and trout, salmon, and other fish species for aquatic systems. We recommend that particular attention be given not only to the usefulness of individual species, but also to the probable need for multispecies monitoring protocols in many systems.

Total Toxicity of Complex Mixtures: We recommend that research be devoted not only to the effects of individual substances, but to the ecological toxicity of complex but common mixtures, such as solvents, agricultural runoff, and wastewater sludges, as well as to airborne chemical mixtures subject to downwind deposition. Mixed types of perturbations such as those involving soil colloids and industrial chemicals, or acid deposition coupled with forest harvesting, also require study.

Movement of Pollutants Out of Sinks: Large quantities of toxic pollutants from past disposal are already present in the environment, stored for unknown time periods in ecological "sinks" such as wetlands, other underwater sediments, landfills, and others. Many pollutants may move across media, however. We recommend long-term research to identify the conditions under which these materials and their conversion products could move out of such sinks and reenter ecosystems and human environments, and rates at which such movement could occur. Research is also needed on the potential for in-place detoxification and immobilization of such hazardous sinks, and on the possible ecological and human health risks of such alternatives.

Human Exposure: We recommend that particular attention be given to developing actual data on human exposures from all environmental sources: for inhalation in the ambient air, in the workplace and other indoor environments; from smoking and other consumer products for ingestion of food and water; and for absorption of some substances by skin contact. In setting priorities, we recommend that consideration be given to what substances and mixtures pose the most significant and widespread hazards and to what variables to monitor and what monitoring methods to use. This line of research clearly deserves increased long-term attention. Little is also known about the relative importance of small numbers of acute exposures versus low-dose, chronic exposures; better understanding of these issues can only occur with increased research on actual exposure patterns.

Multiagency Studies. The research needs detailed above cut across not only programmatic lines within agencies like EPA (such as with EPA's air and water quality and toxic substances programs), but also the boundaries dividing EPA's regulatory responsibilities from those of the Occupational Safety and Health Administration, the Consumer Product Safety Commission, the National Centers for Disease Control, and others. The Panel therefore encourages the initiation of coordinated research and monitoring studies of exposures, involving both the relevant regulatory and research agencies.

Effects on Multiple Organs and Physiological Systems. We recommend the expansion of health effects studies to cover a broader range of possible health effects than are conventionally included in current research efforts, which are focused on studies of cancer and genetic mutations. Logical extensions of research efforts would be expanded studies of neurobehavioral and immune systems.

Climate Perturbations. Most analysts estimate that fossil fuel combustion will increase worldwide, and that the magnitude of possible effects on global temperature, carbon cycles, and other parameters will similarly increase. Other manmade impacts for which some scientific data suggest potentially significant climate effects include tropical deforestation, long distance transport of atmospheric pollutants, and large numbers of nuclear explosions. We recommend that continuing and intensified research attention be devoted to these potential perturbations and their effects.

Biotechnologies. The current knowledge explosion permitting genetic manipulation of biological organisms makes possible potentially vast changes in natural ecosystems and human health, and in humanly managed agricultural, forest, and aquatic ecosystems. Although many of these changes may be beneficial to human well-being, the potential also exists for serious unintended adverse effects. Given the self-reproducing nature of some new biological organisms, we recommend that research on possible consequences be at least as thorough as that on product development.

Linkages Among Ecological Systems. We recommend the expansion of research on the transport and fate of materials between heterogeneous ecosystem units, such as the movement of soils and their residual chemicals from agricultural lands into streams and lakes, and the movement of chemical pollutants both downward through the unsaturated soil zone into groundwater and laterally in groundwater.

Monitoring

For the monitoring component of data collection for environmental management purposes, we recommend that attention be given to the following types of studies:

Reassessment: We recommend as a short-range research need that a systematic reassessment be conducted of the breadth of major environmental monitoring systems that are now in operation, the uses, values, and limitations of these systems, and the extent to which these systems serve or fail to serve the expected future needs of long-term environmental research with special attention to what are broadly called toxic chemicals. This reassessment should include substantial involvement of research scientists who are the ultimate users of monitoring data. The most successful monitoring programs in terms of both viability and usefulness appear to be those that have direct and accountable ties to user communities.

We recommend the establishment of a separate professional environmental data or monitoring unit to serve the needs of researchers and managers for accurate data, to generate more effective involvement and oversight on the part of the scientific community, and to stimulate more productive discussions between theorists, instrumentation specialists, and data collectors.

We recommend that all new environmental monitoring programs be peer-reviewed initially and audited at regular intervals by independent statisticians to assess the validity and reliability of their design and operation. Such a review could involve specialists in such fields as remote sensing and data transmission and integration, to ensure that the most cost-effective and dependable data collection and analytical technologies are used.

Biological Indicators of Ecosystem Health: We recommend the expansion of research efforts on both ecologically significant endpoints for regulatory attention and on species that provide early precursors of possible ecological harm.

Sensitive Populations: We recommend research to monitor populations at risk that have a likelihood of serious exposure and health effects by virtue of their biological susceptibility or their high probability of significant exposure. Examples are occupationally exposed workers, pregnant women, and others at particular risk. We recommend that research studies be undertaken on both the health of such subgroups and on the significance of their responses as precursors of effects on others.

Integrated Data Bases: We recommend as a long-term research goal the development of integrated data bases providing better data than are currently available on the flows of combinations of hazardous materials both into and among ecosystems, and through multiple exposure pathways to human health effects. As initial steps, we recommend that particular attention be given to linking quantitatively the monitoring data sets on discharges, environmental transport, exposures, and human health effects, for such common substances and mixtures as lead and benzene. We also recommend design studies in which environmental monitoring is combined with more detailed medical surveillance of small groups. In some cases environmental monitoring could be added to experiments where small groups are already being studied on a long-term basis.

Health Risk Assessment and Environmental Impact Assessment Techniques

The Panel has adopted the following recommendations relative to human health risk assessment and environmental impact assessment techniques:

Risk Assessment: For health risk assessment, we recommend emphasis on the the following research needs:

Basic Mechanisms. A central need is for better understanding of the dynamics of ecological and physiological systems under stress, and of the mechanisms by which particular stresses cause adverse health effects.

Noncarcinogenic Effects. In particular, more research is needed on mechanisms and effects other than cancer, since attention so far has been devoted almost exclusively to cancer rather than to other effects that could be equally serious: effects, for instance, on reproduction and genetic mutation, on neurobehavioral development, and on the immune system.

Exposures. Exposure data are often weak in QRA, deriving from inferences from only one or a few limited studies (if any) rather than systematic evidence. Monitoring of sensitive groups, and other studies linking environmental monitoring to medical surveillance, would help to fill this gap.

Short-Term Tests. Short-term bioassay techniques are now being developed and tested as possible alternatives or adjuncts to the long-term bioassays now used to test chemical toxicity. These techniques, if successful, appear to be the best hope for screening enough substances quickly and cheaply enough to match the rate at which new substances are synthesized and introduced into commerce. Additional long-term research will be needed to develop and refine these techniques, especially for noncarcinogenic effects as well as cancer.

Social Sciences Research. Current social sciences research on decision processes and on the bases for QRA inference and assessment guidelines can provide a useful context for incorporating in QRAs the influences of publically held values and attitudes, criteria for setting risk priorities, and those factors that influence public understanding of risks.

Validation Studies. Risk assessments should be subjected to independent validation studies both to identify points of weakness and to evaluate their sensitivity to alternative assumptions and models.

Environmental Impact Assessment Techniques: We recommend that research attention be devoted to the following issues relating to possible improvements in environmental impact assessment techniques:

Ecosystem Dynamics. Research attention is needed to basic flows of materials and energy, natural fluctuations in these processes and in representative species populations and interspecies interactions, responses to both manmade and natural stresses, the transport and fate of toxic substances in ecological systems, and linkages between media and ecosystems. A primary focus would be on long-term studies of stressed ecosystems and long-polluted sites, where baseline data and some long-term monitoring already exist and potentials for recovery and rehabilitation can also be investigated.

Consistent Baselines and Monitoring. Continued research attention is needed to the establishment of reliable monitoring networks for basic parameters across a wide geographic range of sites and ecosystem types. Much of this could probably be done by better coordination among existing sites and organizations, as is now beginning to occur for acidic deposition phenomena.

Retrospective Validation. Thousands of EIA studies have been completed, but rarely, and never on a regular basis, has their validity been evaluated. Additional retrospective evaluations should be conducted of the predictive validity of EIAs, and recommendations developed for improving their methodology where appropriate.

Modeling and Forecasting Techniques

Such techniques are viewed by the Panel as critical tools to assist environmental management. We recommend particular attention to the following long-term research needs for these tools:

Verification: We recommend that existing models be verified before development of new ones proceeds. Verification studies should include clear documentation of each model, analysis of the model's sensitivity to particular assumptions and design criteria, discussion of why particular hypotheses or theories were chosen rather than competing ones, testing where possible against actual time series data (requiring links to the improvement of monitoring, discussed above), and verification of the mechanisms postulated by the model as well as the outcomes.

Simplification: As simulation models become very complex, verification and comprehension become difficult. Some large models may be too stable, and thus they will not accurately represent stresses that could in reality cause sudden qualitative change in the system. A research effort should be made to simplify environmental models as an aid to understanding.

Interactive Modeling: One of the important potential benefits of quantitative modeling is as a direct aid to management problem analysis and decisionmaking. To achieve this end requires modeling capability that is relatively simple and transparent and highly interactive with the users. We recommend long-term research on interactive techniques for management modeling at a widely usable level, such as with current microcomputer technology, and training efforts to encourage testing and refinement of such techniques in actual management situations.

Adaptive Phenomena: We recommend long-term modeling research on the dynamics of ecological system adaptation or non-adaptation to stressors, including especially the conditions under which qualitative changes might occur in the system that would be either adaptive or pathological.

Environmental Management Approaches

Discussions at the panel meeting on extant and alternative environmental management strategies were focused on three issues requiring substantial research attention. These issues were (1) environmental management research, (2) the administration of environmental programs, and (3) the institutional framework for environmental management.

Environmental Management: We recommend the following long-term research emphases to foster achievement of better integration of both the understanding and the goals of environmental management strategies:

Interdisciplinary Studies in Ecosystem Management. Studies are needed to link research and monitoring of the dynamics of stressed ecosystems, especially in important types such as wetlands, estuaries, and agricultural ecosystems, with experimental evaluation of alternative management strategies. Such studies require substantial periods of time for completion, as well as interdisciplinary cooperation among a substantial range of natural and social science and engineering disciplines. One particular need is for studies of rehabilitation strategies for degraded ecosystems.

Cross-Media Management Strategies. When pollutants are released into the environment, they may be discharged either to the air, the water, or the land. When they are treated, they may in part be rendered less harmful, but in fact they may simply be transformed: for instance, a decrease in water pollution may create an increase in sludge. Pollution control programs are often focused by media, a factor that limits the development of multimedia solutions to pollution. Long-term research is needed to develop and test strategies for monitoring cross-media effects, and then for optimizing pollution control strategies both across the several media and across multiple routes of human exposure.

New Technology Management. Long-term research is needed on the possible ecological effects of new technologies such as biotechnology, and on scientific resources available to anticipate particular consequences.

Interagency Coordination. Many of the needs identified by this Panel cut widely across existing agencies and programs. We believe that CEQ could foster the implementation of this research agenda. Particular attention is needed to issues such as coordination of data collection and monitoring activities, and establishment of a clearinghouse for environmental modeling; to further development and explication of general methodologies for impact and risk assessment; and to generating multi-agency research and management initiatives on key topics, such as ecosystem management studies and regional integrated regulatory experiments.

Related Social Science Research

We believe that attention should also be given to social science research on topics relating to environmental management decisionmaking, the utilization of environmental science, and innovative environmental management strategies.

POLLUTION OF THE NIAGARA RIVER

Question: CEQ, as part of its responsibilities is supposed to "advise and assist" the President and agencies in achieving international cooperation for dealing with environmental problems. One of the most vexing international environmental problems is the pollution of the Niagara River. Have you made any recommendations or taken any other actions regarding this problem?

Answer: Since EPA has been addressing this issue, CEQ has not made any recommendations pertaining specifically to the quality of the water in the Niagara River. However, a Member of the Council, who served as EPA Region II Administrator during 1982-1984, was particularly active in carrying out an EPA initiative begun in April, 1982 to identify and address all potential sources of contamination of the Niagara River from Western New York State. The two "Niagara Frontier" counties of Erie and Niagara constitute a major center of heavy industry, particularly steel, automobiles and chemicals, thanks largely to the relatively inexpensive electricity supplied by the powerful and abundant waters of the Niagara River as it flows over the famous cataract and into Lake Ontario. Although the local economy is changing, many pollution problems created over several decades are only now becoming well understood. EPA prepared a series of quarterly status reports on its "Niagara Agenda" (an example is attached) that served as the basis for regular progress meetings among EPA, New York State, Environment Canada, and the Ontario Ministry of the Environment. EPA was particularly concerned about the quality of the drinking water from the U.S. and Canadian sources that take in raw water from the Niagara River. We have attached a summary of the study that EPA's Office of Drinking Water prepared as part of the Niagara Agenda. More current information may be obtained from EPA's Region II Office of External Programs.

Report on Task 6 of the Niagara Frontier Agenda - An Evaluation of Contamination and the Adequacy of Monitoring at Public Drinking Water Supplies in the Niagara Frontier

Report Prepared by Stig Regli
Environmental Engineer

Project Manager
Joseph A. Cotruvo, Director
Criteria and Standards Division

Task 6 Project Leader
Victor J. Kimm, Director
Office of Drinking Water

Introduction

In April of 1982, the Niagara Frontier Agenda was developed by the U.S. Environmental Protection Agency (EPA) and the New York State Department of Environmental Conservation (DEC) to assist the State of New York to monitor progress in the assessment and environmental clean-up of various facilities in the Niagara Frontier. One element of the Agenda, established to address the public concern for chemical contamination of drinking waters, was designated as "Expanded Monitoring of Public Water Supplies" (Task 6). The Office of Drinking Water (ODW) was asked to direct this task, having the objective to evaluate the extent of contamination at drinking water utilities along the Niagara River, to determine the adequacy of existing monitoring, and to make recommendations for additional monitoring as needed.

In attempting to fulfill the above objectives, certain questions needed to be answered. What are the actual and potential sources of contamination to each public water supply in the Niagara Frontier? Are existing data and monitoring sufficient to indicate whether or not there is significant contamination to the various drinking waters? Are the existing data and that being generated with ongoing monitoring of acceptable quality? For perspective, how does the Niagara River compare with other industrialized river basins, in regard to chemical contamination, as a source for public drinking waters? If existing data and monitoring do not adequately answer these questions, what additional monitoring is needed and how can this most effectively be accomplished? Are there unique monitoring applications that could improve or replace existing protocols? The scope of work used to address these questions is discussed as follows.

Scope of Work

From June through mid-October of 1982 the Office of Drinking Water (ODW) began its review of available data and identified various organizations involved with monitoring in the Niagara Frontier. On October 20 the ODW participated in a field trip with representatives of DEC and the Province of Ontario Ministry of the Environment (MOE) to gain additional perspective on the location of major industrial and hazardous waste sites relative to the raw drinking water intakes of public utilities in the area. Subsequently, a meeting was held in Buffalo at the DEC regional office to collect and discuss information reflecting actual and potential contamination to drinking waters, to identify data deficiencies, and to identify ongoing and proposed monitoring. Participation included the New York State Department of Health (NYSDOH), DEC, MOE, Environment Canada, Department of Health and Welfare-Canada, and the EPA (Headquarters, Region II, and Region V). The agenda, list of participants, and summary of the highlights of the meeting are given in Appendix A.

Since the meeting, additional data have been received and analyzed by the ODW. A complete listing of information that has been reviewed for this report is given in Appendix B. Data considered most significant was analyzed, to the extent possible, for its quality by the ODW (see Appendix C). This includes drinking water data generated by the City of Niagara Falls, by MOE, EPA, and by the NYSDOH.

Extensive monitoring is still underway by the Niagara River Toxics Committee (NRTC-participation includes representatives from DEC, MOE, Environment Canada, and EPA) to characterize contamination in the Niagara River, in some cases including areas near drinking water intakes. The ODW is participating in a NRTC subcommittee for evaluating the quality of, and the setting of quality control criteria for, data generated in the various monitoring programs. Much of this work is still not completed and could not be included in this report.

The ODW is also participating in the NRTC subcommittee to determine long term monitoring needs so as to measure the success of remedial programs and to indicate trends of quality of the Niagara River. Although it appears that this subcommittee will recommend long term monitoring of certain raw drinking waters as a subset of ambient water quality monitoring, these recommendations have not yet been established and could not be included in this report.

Additionally the United States and the State of New York are co-plaintiffs in a lawsuit, United States, et al. v. Hooker Chemicals and Plastics Corporation, et al. ("S" Area Landfill), which will address monitoring required to detect chemicals from one source - Occidental Chemical Corporation "S" Area landfill. Because the matter is in litigation, this report will not discuss the future monitoring requirements related to the lawsuit.

Most of the ambient water quality monitoring in the Niagara Frontier has consisted of grab sample collection and its subsequent analysis. When concentrations of chemicals are very low and possibly variable because of variation in source contamination (e.g., irregular industrial discharge, runoff from storm events), the grab sample analytical approach is often inefficient and costly for providing the desired information.* Appendix D provides some background information on several analytical techniques which may provide additional useful information on the water quality.

This report has been reviewed by representatives from the NYSDOH, DEC, and EPA (Headquarters, Region II, and Region V). Individuals that participated in the review are given in Appendix E.

This report reflects the available technical data as of March 1983. On-going studies in the Niagara area since March 1983, could modify some of this report's recommendations and conclusions.

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*Standard practice in monitoring for industrial discharge is to take 24 hour composite samples. However, this is generally not done for ambient water quality measurements. The exception to this are monthly composite samples by DEC and MOE, over 24-72 hour intervals, at the beginning and end of the Niagara River. Analysis of this data is not complete and could not be made available for this report.

Summary and Conclusions

There are presently ten public water systems in the Niagara Frontier serving a population of about one million people. Locations of all the raw water intake points for these communities are indicated in Figure 1. The population served, daily output, and treatment processes provided at each plant are indicated in Table 1. Niagara Falls of Ontario is the only Canadian community now drawing raw water from the Niagara River. Since July of 1982 the Canadian communities of St. Davids and Niagara on the Lake (indicated as sites 11 and 12, respectively, in Figure 1) shifted their source of water, primarily because of technical convenience and economics, from the Niagara River (St. David's withdrew water from the power canal but this was effectively, because of flow diversion, the Niagara River) to the treated water piped from the St. Catherine Supply, whose raw water source is the Welland Ship Canal (whose source is Lake Erie).

All of the drinking water treatment systems include disinfection, coagulation, sedimentation, and filtration and six intermittently use powdered activated carbon. Filtration at all plants is significant in that it provides a treatment barrier for certain chemicals that, if present, are generally attached to suspended solids (e.g., PCBs and often heavy metals). However, many other chemicals are not attached to suspended matter and, if present, would not be significantly removed by the above treatment processes.* Because of this there is concern for chemical contamination to drinking waters from point and non-point sources of pollution. Locations of major U.S. point sources of chemical substances and of hazardous waste disposal sites (does not include Canadian sources) are illustrated in Figures 2 and 3. Identification of these locations are given in Appendix F. Table 2 characterizes the major known chemical discharges into the Niagara River. The hazardous waste sites indicated in Figure 3 are mostly inactive and their contributions of chemical substances to the environment are not well defined. These waste disposal sites may contribute contamination to the river via surface runoff, or groundwater leaching, and in one instance through direct industrial discharge of contaminated groundwater used for cooling or industrial processes.

Despite the various contaminant sources in the area, the Niagara River appears to be of relatively good quality as a raw drinking water source, because of dilution from the large volume of flow (approximately 200,000 cubic feet per second at the mouth and 80,000 cubic feet per second in the heavily industrialized east branch). Based on measurements of organic priority pollutants in raw water at water treatment plants, the Niagara River appears substantially less contaminated than the four other industrialized river basins in the U.S. for which data were collected.

Monitoring data by MOE of raw waters at Niagara on the Lake and Niagara Falls, Ontario were used to represent the Niagara River in Appendix G. The worst case situation that occurred at either of Niagara on the Lake or Niagara Falls, Ontario was selected for representation. These data were selected because (1) they represented an extensive multi-compound analysis of a drinking water conducted with high frequency for a sustained period, (2) enough information was available to analyze the quality of these data and to determine that this was acceptable (accurate limits of detection of .1 ppb for all compounds except methylene chloride and benzene - see Appendix C),* and (3) the sampling point, Niagara on the Lake is downriver from all toxic discharges into the Niagara River. The City of Niagara Falls is the only other public drinking water supply in the Niagara Frontier with regular monitoring of toxic chemicals other than those required by the NIPDWR (i.e., pesticides, heavy metals and trihalomethanes). These data were not selected in this particular analysis. The four indicator chemicals which are monitored five times per week are examined to determine if "S" Area chemicals are present - not to provide an inventory of chemicals in water. Since January 1982, the City of Niagara Falls has monitored monthly for volatile organics using EPA method 624. This includes 40 to 50 chemicals in addition to the indicators. The Niagara-on-the-Lake monthly monitoring includes scans for a wider range of chemicals. Although the nominal detection limits for the latter data are lower (0.1 ppb vs a range of 0.01 to 5 ppb) the Niagara Falls data are by GC/MS and therefore are less susceptible to false positives. Contamination at this site has been identified as coming from migration of chemicals through the ground into the intake structure and not from the river itself, therefore the influent and effluent is not a good measure of the quality of the Niagara River.

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*The use of powdered activated carbon at high concentrations, would remove many organic chemicals if present, but this would not be an efficient nor economical long term treatment approach. Currently treatment plants use powdered activated carbon most of the time at low concentrations (less than 5 mg/l) for taste and odor control.

All available data for the City of Niagara Falls and a history of the groundwater contamination into the intake structure, are given in Appendix H. An analysis of the quality of the data generated by the City of Niagara Falls laboratory is given in Appendix C.

A case-by-case analysis of actual and potential contamination for the other public drinking water supplies in the Niagara Frontier, and the adequacy of existing monitoring to indicate this, is given in Appendix I.

Major findings of the entire study are given as follows.

1. The City of Niagara Falls and Lockport are the only water treatment plants in the Niagara Frontier with apparent sources of chemical contamination in the immediate area of their intake structures.

2. Concentrations of heavy metals and pesticides in raw waters at all the water treatment plants in the Niagara Frontier have been consistently below the NYSDOH drinking water guidelines and standards. The exception to this has been the occasional occurence of high levels of iron which poses no health problem. Iron is regulated by the DOH for aesthetic rather than health reasons (i.e., for concern for taste and possible discoloration in laundry washing).

3. All drinking water intake points in the heavily industrialized east branch of the Niagara River are from 1300 to 5800 feet from the shoreline. The high volume and fast flow of the Niagara River, should provide extensive dilution of any contamination originating from the shoreline. Considering this and that the most significant point source discharges (Olin, Hooker Specialty, and the wastewater treatment plant of the City of Niagara Falls - see Table 2) of toxic organic chemicals into the Niagara River are downriver from all raw water intake points, it is unlikely for significant contamination to occur at any of the raw water intake points. Other than for the City of Niagara Falls, Niagara Falls Ontario and Niagara on the Lake, few actual measurements of organic chemicals (other than pesticides), however, exist to verify this likelihood.

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*Because of the uncertainty of these numbers, and the desire for a worst case situation, measurements for these compounds were included in Appendix G, Figures 1-4.

4. No significant contamination would be expected at the raw water intake points to the water treatment plant of the City of Niagara Falls. All the major chemical discharges from the City into the Niagara River occur downriver from the water treatment plant (all indicated under Niagara Falls in Table 2). Inactive hazardous waste disposal sites that may be leaching chemicals into the Niagara River upriver of the water treatment plant include the 102nd Street site (Hooker, Olin), Griffon Park, and Love Canal (via Cayuga Creek). Love Canal and 102nd St are being addressed by lawsuits and a superfund feasibility study is being performed at Love Canal in order to determine what additional remedial measures are necessary to prevent further migration of chemicals into the Niagara River. The raw water intake in the East Channel is, however, 1750 feet from the shoreline and because of the large and fast Channel flow, chemicals that might leach from these waste sites are unlikely to occur at significant concentrations in the water at the intake. Since January 1982, the City has conducted monthly analyses for the presence of 40-50 volatile organics in their tap water. Other than for the indicator compounds of groundwater contamination, measurements were mostly below detection limits. Although not conclusive, because detection limits ranged from 0.01 to 5 ppb (higher than those for the indicator compounds), these data appear to support the likelihood that no significant contamination exists at the intake points (since the chemicals analyzed for in the finished water would not tend to be significantly removed by the treatment processes).

5. Chemicals in groundwater were leaching into the intake structure of the water treatment plant at the City of Niagara Falls (U.S.) and causing low level contamination of the drinking water. The chemicals are apparently leaching through the ground from the nearby "S" Area hazardous waste site. No contamination by these chemicals is apparent at the two raw water intake points in the Niagara River.

6. Since August of 1979, the City of Niagara Falls U.S. has monitored for indicator compounds (trichlorobenzenes, hexachlorobutadiene, hexachlorocyclopentadiene, tetrachlorobenzenes) in the finished water (3-7 times per week) and in the raw water contained in the shoreshaft, pump station forebay, and chemical pretreatment channel (generally weekly). The average of the sums of the indicator compounds in finished water since the City began its intensive monitoring was highest in the months of August 1979 (3.57 ppb), September 1979 (1.57 ppb), October 1979 (1.06 ppb), and October 1982 (1.36 ppb). All other months had average sum concentrations of less than .75 ppb in the finished water, including November 1982 (.45 ppb) and December 1982 (.34 ppb). Higher concentrations were reported in the raw water indicating some removal by the treatment plant (probably attributed to the use of powdered activated carbon).

7. Because of the increased presence of the indicator compounds in the main intake structure and raw water, on October 22, 1982, the NYSDOH issued an administrative order. (see Appendix I, Attachment H-16). The City was ordered to submit an emergency plan to the DOH including intensified monitoring; increased inspection and cleaning of the intake structure when needed as indicated by monitoring; modification of plant operations so as to be able to treat, if indicated by monitoring, increased levels of contamination; and provision of adequate water supply if use of the bedrock tunnel is terminated. In response to this order and its subsequent investigations during their Fall 1982 diver cleanup program (see Appendix H, Attachment H-17), the City closed the main intake line in early April 1983 and is drawing all needed water from the secondary intake line.

8. Based on extensive monitoring in the Love Canal Area, no evidence was found that drinking water was directly contaminated by infiltration of contaminants from Love Canal into the water distribution systems of the City of Niagara Falls. The observed

variability in concentrations of substances detected in drinking water could not be distinguished from either measurement error or day to day fluctuations in finished drinking water quality normally observed at the City of Niagara Falls Water Treatment Plant. Analysis for over 100 different organic chemicals from at least 26 different residential taps indicated very few occurrences, other than trihalomethanes (THMs), above detection limits. THMs, which occured well below the Maximum Contaminant Level (MCL), are formed as a result of chlorination in the treatment process and their presence does not indicate contamination from Niagara River or infiltration into the intake structure or distribution systems.

9. The quality of much data existing prior to the NRTC project (particularly pesticides) could not be reviewed because of insufficient record keeping and the subsequent uncertainty of adherence to essential quality control criteria. Major findings by the ODW on significant data which was reviewed are given as follows (more detailed analyses of various data is given in Appendix C). For the analyses conducted by the City of Niagara Falls for the indicator compounds values above 0.1 ppb should be considered approximate. Reported concentrations of below 0.1 ppb should only be considered as qualitative evidence of the presence of that contaminant. For analysis conducted by the MOE for purgeable compounds in raw and finished water at Niagara Falls, Ontario and Niagara on the Lake quantification limits should be considered at .1 ppb. Compounds detected less than 0.1 ppb should only be considered qualitatively present. Without GC/MS confirmation of the data, there is the possibility of false positives. Measurements of methylene chloride and benzene are questionable because these compounds were used as extraction solvents and the identifications could have resulted from laboratory contamination.

10. In 1978, the City of Lockport identified leakage into their intake line at the shoreline near the pump station. Monitoring of raw water by the City of Lockport indicated concentrations of 25.6 ppb (para-dichlorobenzene), 8.1 ppb (meta-dichlorobenzene), and 1.1 ppb (1,2,4,5 tetrachlorobenzene) in one sample. Hooker Durez discharges waste containing these chemicals and others via a combined sewer having an outlet in a small alcove at the shoreline within a few hundred feet of the Lockport drinking water intake line (the drinking water intake point from the Niagara River is actually 2550 feet from the shoreline and upriver from any possible contamination from Hooker's waste discharge). The City has repaired the intake line, apparently eliminating the leakage that was occurring, and is conducting biannual diver inspections to verify this. Monitoring by the NYSDOH in August of 1982 of 108 chemicals in the raw and finished water, including compounds previously detected, indicated no levels above detection limits (1 ppb for compounds identified as present in the 1978 monitoring and generally 1-10 ppb for other compounds). The NYSDOH conducted additional monitoring in June of 1983. No chemicals were found above detection limits in the raw and finished water except for low trace levels of chlorobenzene in the raw water. The NYSDOH will continue with follow-up monitoring.

11. Most ambient water quality monitoring in the Niagara Frontier has consisted of grab sample collection and their subsequent analysis. Because of chemicals occurring at low concentrations and/or at variable concentrations (e.g., occurrence often being a function of irregular industrial discharge) this approach is often expensive and inefficient in providing representative water quality measurements. Other sampling approaches are needed that can more cost effectively be used to provide the desired information.

12. Much of the past monitoring in the Niagara Frontier has not been coordinated so as to optimize the information being generated. Also, quality control criteria regarding sampling and analytical protocols, detection limits, and data reporting have varied

significantly for the different organizations involved. Many of these problems are currently being addressed by the Niagara River Toxics Committee. Continued coordinated efforts in this regard are essential to optimize all monitoring conducted in the area.

Recommendations

1. Monitoring of the indicator compounds of groundwater contamination at the City of Niagara Falls should be continued as practiced and recommended by the NYSDOH.

This includes the provision by the City of more intensive monitoring (see Appendix H, Attachment H-18) in the event that any one of the indicator compounds exceeds 1 ug/l in the chemical pretreatment channel.

2. Currently the City is conducting monthly monitoring for 40-50 volatile organic chemicals in its finished water but with detection limits sensitive to 1 ppb or more (with the exception of indicator compounds and pesticides - see Appendix H, Attachment H-15). Contamination at the raw water intake point of the City of Niagara Falls is unlikely; additional monitoring can be conducted to verify this. The most significant toxic chemicals identified as entering the Niagara River from point and nonpoint sources upriver from the water treatment plant (based on monitoring by the NRTC-results not yet available) should be monitored for presence in the City's raw water. The City of Niagara Falls should continue its present monitoring system with analyses reported at 0.1 ppb and below for the four Occidental chemicals on a daily basis and 21 other compounds on a monthly or quarterly basis. Ongoing evaluation of the monitoring program should be continued to determine the nature and extent of future monitoring.

3.) At the City of Niagara Falls, analyses to date have been mainly conducted on the 129 EPA priority pollutants and approximately 20-30 other target organic compounds (see Appendix H). Also, the analysis identified the next 20 most abundant, non-target chemicals.(16) To provide additional data on other chemicals potentially in drinking water, a more comprehensive analysis is suggested. Rather than identifying/quantifying specific target chemicals as generally previously practiced, another approach would be broad spectrum "detective" oriented, attempting to answer whether other organic chemicals of potential health significance are present.

An analytical approach that attempts to meet such objectives, called the "Master Analytical Scheme" (MAS), is being developed by the EPA. The MAS defines a set of protocols that allow for sample collection and analysis of a broad spectrum of chemicals well beyond those considered in the EPA priority pollutant list. The state-of-the-art MAS should be available for application in mid 1984; and EPA will include a few samples from the Niagara area as part of a method evaluation project that will be operating at that time.

Samples of the finished and raw water from the intake point in the Niagara River for the City of Niagara Falls, and from a few other locations in the area, for perspective, should be considered for one time broad spectrum chemical analysis using the MAS protocol (21) when it is available.

This analysis can be supplemented with Grob Closed-Loop Stripping Analysis (CLSA)(22) to allow for lower limits of detection (parts per trillion range) of a wide range of purgeable organics. CLSA has been used successfully for several years by EPA laboratories for the analysis of over 200 organic chemicals in drinking waters.(22)

These state-of-the-art comprehensive analyses should be performed by one or two qualified laboratories under strict quality control conditions using appropriate quality assurance protocols. This would provide the necessary analytical data support to assure validity of the reported findings.

4. Monitoring for TOX (total organic halogenated compounds) should be considered as a potential screening mechanism for determining chemical contamination occurring upriver from drinking water utilities. TOX is a measurement (with a detection limit of about 10 ppb) of the sum of a broad spectrum of halogenated organic compounds, including compounds which cannot be specifically analyzed but which could serve as a general indicator of such contamination and/or the trigger for conducting specific compound analysis. Possible sampling locations could be near or at sewer outfalls, industrial discharges, and points off-shore from hazardous waste sites. Following the detailed characterization of toxics into the Niagara River by the NRTC (still in preparation), appropriate TOX sampling sites, if any, could be selected.

Based on available data at this time, monitoring for TOX is recommended at the end of the Little River (entering the Niagara River), upriver from the City of Niagara Falls raw water intake point. Significant changes in TOX concentration could indicate increased leaching of halogenated organics from hazardous waste sites in the upriver area (e.g., Love Canal, Griffon Park, 102nd Street sites or outfalls) and act as a possible trigger for multi-specific compound monitoring of halogenated organics downriver at the water treatment plant. If TOX measurements at the proposed Little River sampling point are high, TOX monitoring would also be recommended for the raw water of the City's water treatment plant. Differences in TOX at the two monitoring points should indicate the mitigating effects of dilution and whether contamination at the Little River sampling point is of any significance downriver at the intake to the water treatment plant, and whether the City should monitor for specific halogenated compounds of concern. Low TOX measurements of the City's raw water, which appears very likely, would have the additional benefit of giving the public added assurance regarding the acceptability of their water. EPA currently has some data on TOX occurrence in raw waters at several locations in the U.S. which could be compared with measurements of the raw water at the City's water treatment plant for added perspective.

5. At the City of Lockport additional monitoring of the raw water appears essential to verify the integrity of the intake structure. Chemicals discharged into the alcove via the combined sewer outfall, include chlorobenzenes, benzene, and meta and paradichlorobenzenes. These compounds should be monitored in the Lockport raw water at times of maximum contaminant discharges from the outfall. Weekly analysis for a period of two months with an analytical sensitivity of .1 ppb is suggested. If no contamination is detected during this period, monitoring should be continued on at least a quarterly basis to verify the maintained integrity of the intake structure. The toxic discharge into this combined sewer line should be eliminated or relocated downriver from the alcove. In this event no monitoring, other than for those chemicals regulated by the DOH, would be recommended.

6. A sampling/analytical approach should be developed that is more efficient and less costly (than grab sampling) to obtain representative water quality data. An approach needs to be developed that would allow measurement of organic chemicals occurring in water at any one time during an extended period and/or occurring at low concentrations over an extended period. One possible approach involves concentrating chemicals from high volumes of water, for an extended period, onto a core of granular activated carbon, followed by extraction and analysis of chemicals that are present. Other approaches that should be considered involve using synthetic resins rather than GAC when it is anticipated that the former will more effectively concentrate or allow desorption of particular groups of compounds.

7. Monitoring by the various organizations in the Niagara Frontier should be coordinated to avoid duplication of effort and to add inter-agency focus where needed on particular areas of concern. In regard to the coordination of ambient water quality monitoring and the ongoing characterization of toxic inputs to the Niagara River, much of this is now being done through the NRTC. Ongoing additional coordination, however, is needed regarding how the findings of the NRTC relate to drinking water concerns and subsequent additional monitoring, if any, that might be appropriate at utilities. Long term monitoring of raw water at selected utilities for selected parameters could serve the dual purpose of indicating river quality trends and the effect of remedial measures while also providing public assurance regarding the quality of drinking waters.

The various organizations generating different data should, where applicable, adhere to common quality control criteria. Particular effort is needed to develop inter-agency acceptance on the definition of detection limits and on the reporting of data. A subcommittee of the NRTC has been established to address these needs. It is recommended that quality control criteria that are subsequently developed be presented to the laboratories, not participating in the NRTC but conducting drinking water monitoring, for their possible adoption.

8. On the basis of all available data no additional monitoring at drinking water utilities (other than that already discussed) is recommended at this time. Additional data generated by the NRTC should be forthcoming within the coming year. This should be analyzed to determine if additional monitoring recommendations are appropriate. Of particular interest are reports presently being prepared for the NRTC by DEC that include an updated analysis of point and nonpoint source toxic inputs into the Niagara River. Information contained in these reports would be particularly useful in either confirming the existing analyses given in this report, or indicating previously unidentified sources of contamination near drinking water intake points or structures that might influence other monitoring recommendations.

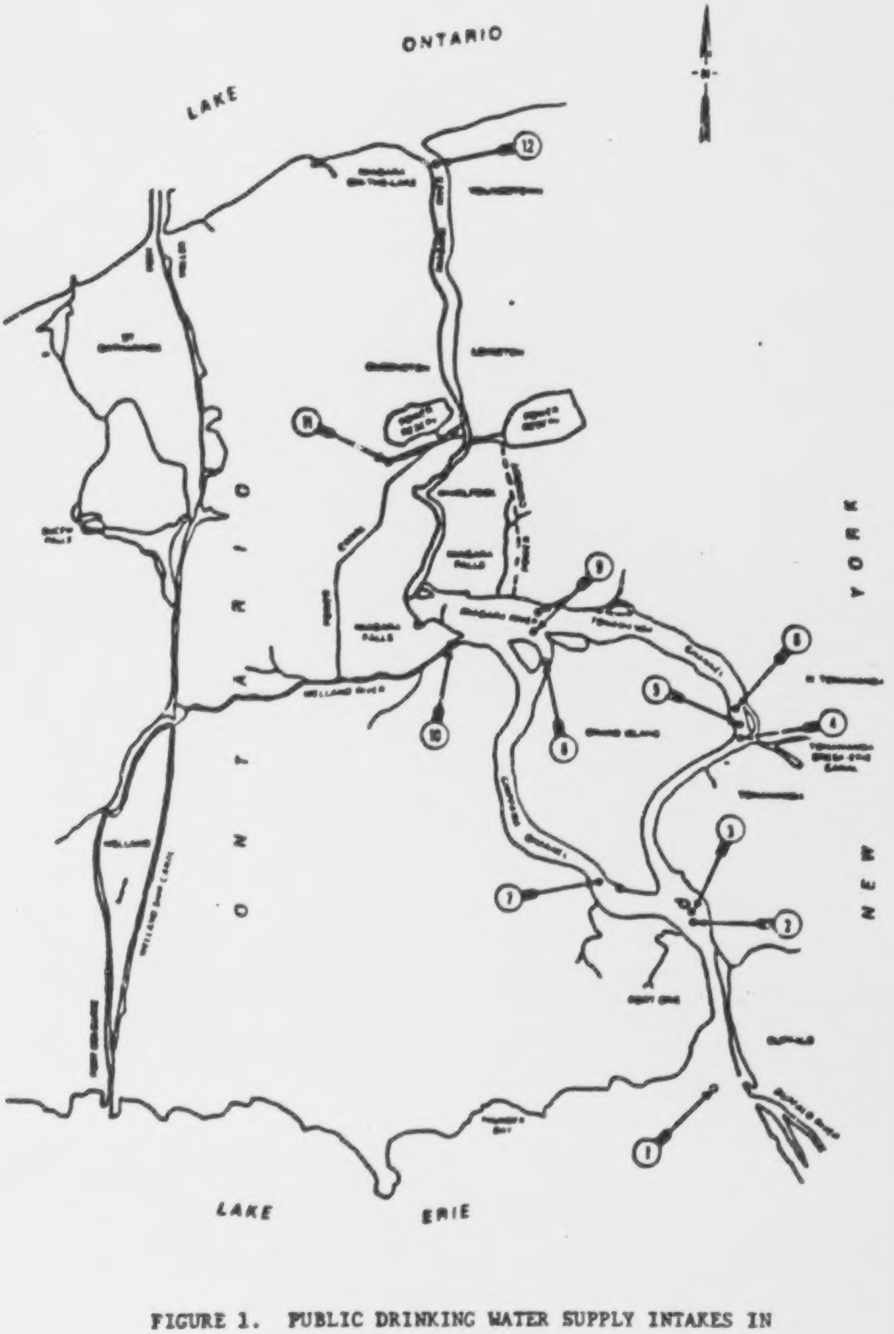
ONTARIO
LAKE
N
12
11
NIAGARA FALLS
9
NIAGARA FALLS
WELLAND RIVER
10
6
8
5
4
O N T A R I O
N E W Y O R K
3
7
2
1
LAKE
ERIE

FIGURE 1. PUBLIC DRINKING WATER SUPPLY INTAKES IN THE NIAGARA FRONTIER

Table 1 - Public Water Systems in the Niagara Frontier*

Intake Location in Fig. 1	Community	Population	Average Production mgd	Treatment Provided
1	Buffalo	400,000	118	disinfection, coagulation, sedimentation, filtration, powdered activated carbon
2	Town of Tonawanda	110,000	12.9	" "
3	Erie Co. Water Authority	140,000**	21.8	" "
4	City of Tonawanda	23,000	5.4	" "
5	N. Tonawanda	38,500	6.8	" "
6	Lockport	26,000	8.5	disinfection, coagulation, sedimentation, filtration
7	Grand Island W. D. #2	6,500	1.4	" "
8	Niagara Co. W. D.	90,000	12.7	" "
9	Niagara Falls	86,000	43.2	disinfection, coagulation, sedimentation, filtration, powdered activated carbon
10	Niagara Falls (Ontario)	70,000	40.0	disinfection, coagulation, sedimentation, filtration

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* Source: New York State Department of Health and the Province of Ontario Ministry of the Environment.

**ECWA has two plants, Van de Water and Sturgeon Point feeding into the same distribution system, serving 375,000 people. Van de Water's current production is 21.8 mgd and Sturgeon Point production is 35.7 mgd. A simple proportion was used to determine people receiving water from the Van de Water Treatment Plant.

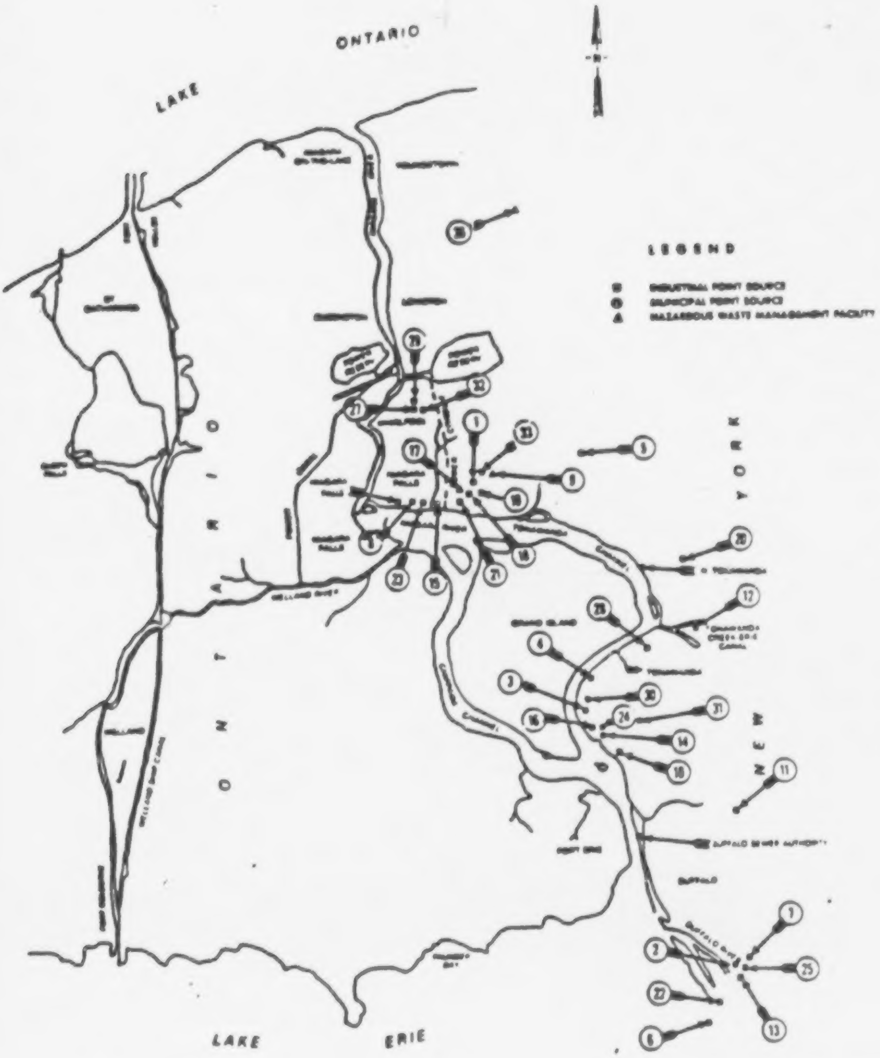
LAKE ONTARIO
LEGEND
INDUSTRIAL POINT SOURCE
MUNICIPAL POINT SOURCE
HAZARDOUS WASTE MANAGEMENT FACILITY
ONTARIO
NEW YORK
WELLAND RIVER
WELLAND SHIP CANAL
GRAND ISLAND
N. TONAWANDA
TONAWANDA
TONAWANDA CREEK-ERIE CANAL
BUFFALO SEWER AUTHORITY
BUFFALO
BUFFALO RIVER
LAKE ERIE
1
2
3
4
5
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FIGURE 2. LOCATION OF MAJOR U.S. POINT SOURCES OF CHEMICAL SUBSTANCES

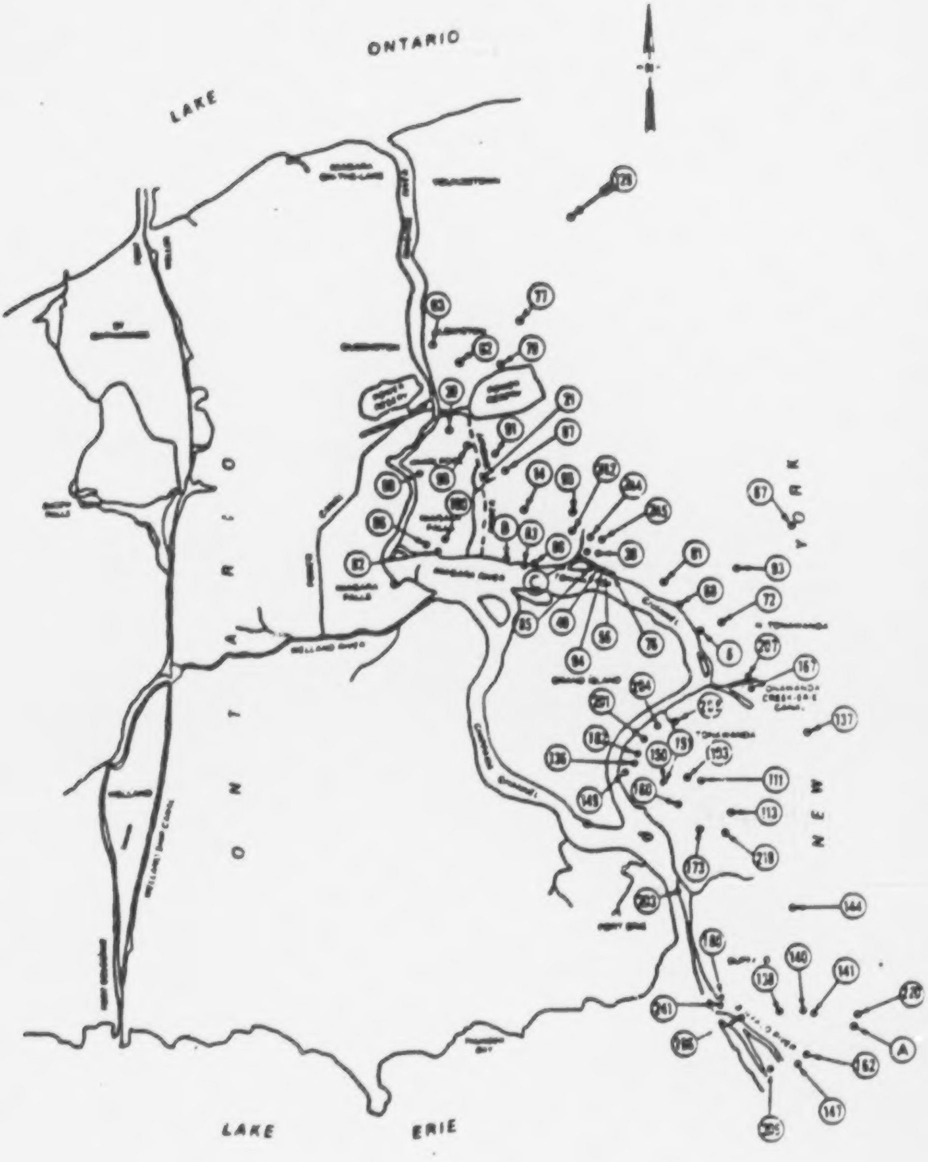
LAKE ONTARIO
ONTARIO
NEW YORK
LAKE ERIE
GRAND ISLAND
128
77
78
21
87
14
217
264
215
67
38
93
72
207
167
137
111
113
219
173
144
140
141
120
A
162
147
C
85
56
76
94

FIGURE 3. NEARBY WASTE DISPOSAL SITES

Table 2 - Chemicals Discharged Into Niagara River (Major Known Point Sources*)

Niagara Falls U.S.A.	Amount (lbs/day) Maximum[a]			Chemicals
	Organic Priority Pollutants	Phenols	Heavy Metals	
Olin	274	4	8	Tetrachloroethylene, trichloroethylene, trans 1,2-dichloroethylene, 1,1,2,2 tetrachloroethane
Hooker Specialty (Occidental Chemical Corp)	100	4	69	Chlorinated toluenes, dichloramine, mirex, hexachlorocyclopentadiene, chlorinated benzenes, trichloroethylene
Dupont	69	2.9	5	Carbon tetrachloride, methylene chloride, chloroform
Municipal W.W.T.P.	252[c]	510[b,f]	42[e]	Carbon tetrachloride, chloroform, methylene chloride, 1,2,4-trichlorobenzene, trichloroethylene, toluene
Tonawanda/N. Tonawanda				
Spaulding Fiber	0	1	175	Zinc
Ashland Petroleum (closed)	0	2.3	242	Antimony (199 lbs), copper (3), lead (17), nickel (15), zinc (8)
Hooker (Durez) (Occidental Chemical Corp)	17	119	4	Chlorobenzene, benzene, dichlorobenzenes

Table 2 Continued

Niagara Falls U.S.A.	Amount (lbs/day) Maximum[a]			Chemicals
	Organic Priority Pollutants	Phenols	Heavy Metals	
Buffalo				
Buffalo Sewer Authority	60[d]	<15[d]	520[d]	Zinc (357 lbs), nickel (69), chromium (60), copper (30)
National Steel	3	22	65	Lead (17.9 lbs), zinc (45 lbs)
Donner-Hanna Coke (closed)	69	25[c]	1[d]	Methylene chloride (54 lbs), benzene (13 lbs)
Republic Steel (closed)	2	0	53	Copper, lead, zinc

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*Compiled and adapted from March 1982 EPA NEIC Overview (ref.   ).

[a] Maximum values reported in SPDES permit application.

[b] From Discharge Monitoring Report.

[c] Long-term average.

[d] EPA May 1981 priority pollutant survey.

[e] EPA-NEIC June 1981 survey.

[f] Twelve month average, July 1980–June 1981.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DATE: [illegible]

SUBJECT: Niagara Frontier Agenda

Jacqueline Schafer

FROM: Jacqueline E. Schafer
Regional Administrator, Region II

Bruce R. Barrett, Director
Office of Water Enforcement & Permits

TO: Lee Verstandig
Acting Administrator

In 1981, EPA's National Enforcement Investigations Center (NEIC) conducted a comprehensive survey of toxic substance pollution in the environment of western New York (Erie and Niagara Counties), commonly referred to as the Niagara Frontier. NEIC's report, published in March 1982 described the progress which has been made in abating pollution over the last ten years. The report also emphasized continued problem areas which required further attention.

In April 1982, EPA announced the Niagara Frontier Agenda, a six category program describing short term activities for the acceleration of pollution abatement efforts on the Niagara Frontier. Progress reports have been prepared for the Administrator's attention on roughly a quarterly basis. These progress reports cover the six major categories of the Agenda, describe the activities within those categories, the progress to date, and the schedules for future activities.

We are pleased to present you with the fourth progress report for the Niagara Frontier Agenda. We would also be pleased to answer any questions you may have concerning the Agenda.

We plan to issue the next progress report in July 1983. Copies of the Niagara Agenda and the first three progress reports are attached for your convenience.

Attachments

I. State Pollutant Discharge Elimination System (SPDES) Permit Issuance

Project Leader: James Vincent, National Enforcement
Investigations Center (NEIC)

Activity: Comprehensive controls on the discharge of toxic pollutants in industrial wastewaters to surface waters of the Niagara Frontier are being implemented through the SPDES permit program. This program is administered by the New York State Department of Environmental Conservation (DEC). EPA is providing technical assistance to DEC in development of the technical bases for permits for 14 major industrial facilities. (Originally, the assistance was for 19 permits. Five facilities have closed or substantially curtailed operations in recent months. DEC is currently reassessing the needs for SPDES permits for these facilities.) Permit conditions specify technology based effluent limitations or more stringent effluent limitations where such limitations are necessary to ensure progress toward attainment of water quality objectives such as those specified in the U.S./Canada Great Lakes Water Quality Agreement of 1978 and New York water quality standards. The permits also contain best management practices (BMP) provisions which require preventive measures and other practices that minimize the improper handling, spills and leaks of toxic or hazardous substances and thereby reduce the release of such pollutants in contaminated surface runoff and groundwater infiltration into industrial sewers.

Status: Attachment I shows the status of permit actions for all 19 permits. DEC has issued final permits to 8 of the 14 active facilities. Draft permits for an additional 4 permits were placed on public notice and have completed the comment period. DEC is reviewing public comments on these preparatory to issuance of final permits. Preliminary draft permits have been completed for the remaining two facilities and are undergoing internal DEC review prior to public notice.

Next Steps: DEC will continue the review of public comments and issuance of final permits for the four facilities during the next few months. The other two draft permits will be placed on public notice within a few months. EPA will provide assistance as requested.

II. City of Niagara Falls Wastewater Treatment Plant Improvements

Project Leader: William Muszynski, Region II

A. Construction Grants

Activity: EPA and DEC will process construction grant applications to accomplish the following objectives: (a) the repair and enhancement of the granular activated carbon filtration beds and the modification of the carbon regeneration system; (b) the improvement of efficiency of the plant operations through the reduction of excessive infiltration and inflow to the treatment plant; and (c) the development and implementation of an approvable pretreatment program.

Status: In addition to the Step I grant increase awarded in September 1, 1982, EPA awarded and, on March 14, 1983, the City accepted a Step III grant increase for the rehabilitation of the carbon filtration and regeneration systems and associated treatment enhancements. The grant requires that facilities construction be completed by January 1, 1985. The total project cost increases to $73,007,656, including the federal contribution of $54,755,742. The City has completed the carbon pilot plant operation for the evaluation of the tolerance of the treatment process to specific pollutants, an essential step in the development of the Industrial Pretreatment Program.

Next Steps: The carbon pilot plant samples are currently being analyzed by the City's consultant as part of a preliminary determination of those pollutants that may not be adequately treated by the plant and therefore must be subjected to pretreatment by industry to assure compliance with SPDES permit limitations. Submission of the pretreatment program is scheduled for June 1, 1983.

B. Technical Review and Support of SPDES Permit

Activity: EPA has provided technical support during the drafting of the SPDES permit and the review of comments on drafts of the permit.

Status: As reported in the last progress report, the Industrial Liaison Committee of the Niagara Falls Chamber of Commerce has brought an action (pursuant to Article 78 of the New York Civil Practice Law and Rules) against the Commissioner of the New York State Department of Environmental Conservation (DEC) in the Supreme Court of the State of New York, Albany County, to vacate the permit and reopen the public comment period on the permit or set a date for a public hearing on the permit. A court hearing originally scheduled for February 11, 1983 has been rescheduled to April 29, 1983.

Next Step: EPA will assist DEC in the review of public comments and will provide technical assistance, as requested, if any evidentiary hearings are conducted.

C. Expedited Litigation

Activity: Expedited completion of litigation to secure injunctive relief to ensure the timely construction of waste treatment facilities and proper operation and maintenance (O&M) of the facilities after completion of construction.

Status and Next Steps: A written progress report was submitted to the Court on March 1, 1983. The next status conference is scheduled for April 12, 1983. Negotiations are proceeding in the interim.

III. Expedited Completion of Active Hazardous Waste Litigation

Project Leader: Whit Field, Office of Legal and Enforcement Counsel

Activity: Expedited resolution of Occidental Chemical Corporation ("Occidental") Litigation.

A. Love Canal

Status: Negotiations with Occidental have been discontinued because of the company's unwillingness to clean up the site voluntarily.

Next Steps: Continue to develop and implement litigation strategies to fast-track the litigation to recover the total cost of cleanup. The litigation consultant team will be reviewing the Superfund work plans. EPA hydrogeological consultants are reviewing, updating, and expanding the Love Canal groundwater computer model.

The implementation of the Superfund remedies is discussed in more detail in section IV. B. below.

B. S-Area

Status: Same as last report. On February 11, 1983, the parties held a telephone conference call with the Judge. Good progress is being made in the negotiations.

.ext Steps: Continue negotiations.

C. 102nd St.

Status: EPA has expanded its contracts with consultants to evaluate the sufficiency of existing data for a determination of appropriate remedial measures to clean up the site. EPA's hydrogeological consultant has submitted several progress reports.

Next Steps: The expanded Love Canal groundwater computer model will also be used in this area when available. EPA is in the process of hiring an expert in bioaccumulation and bioconcentration to study the effects of chemicals from the 102nd Street site in the Niagara River water and sediments. Additional data is being sought from Occidental. When the results of the studies above are available, negotiation will be commenced with Occidental and the Olin Chemical Corporation (Olin operated a landfill adjacent to the Occidental Landfill at this site).

a concrete containment wall and a clay cap. This work included:

- extensions to existing monitoring well casings;
- new effluent pipes from the on-site treatment facility to the City sewerage system;
- modification to storm sewers to accommodate additional runoff from the proposed extension of the clay cap;
- severing and plugging of utility lines;
- removal of trees and hydrants; the cleaning of storm sewers; and
- the decontamination of construction equipment.

Malcolm Pirnie was awarded the contract for five of the studies for the further development of a remedial program. These studies were denoted in Attachment 1 of prior progress reports as follows: Task II, North End storm and sanitary sewer remediation; Task III, Black and Bergholtz Creek remediation; Task IV, South End sewer remediation; Task VI, Delta area remediation at the 102nd Street landfill outfall discharge; and Task VII, Remediation of lift stations and sanitary sewers west of the site. These studies were commenced by Malcolm Pirnie in December 1982.

E.C. Jordan was awarded the contract for development of a long term monitoring program in February 1983. E.C. Jordan has completed a borehole analysis survey which is necessary for the determination of the location for the proposed containment wall. It is in the process of developing the long term monitoring program for the site.

Next Steps: The installation of the site containment wall and the clay cap with synthetic membrane (Hypalon) liner will commence in June 1983 with a scheduled completion in December 1983. Demolition of the 99th Street School and the fencing of Bergholtz Creek will be scheduled during this period as well.

The Malcolm Pirnie studies and the E.C. Jordan monitoring program will be drafted and distributed for public comments in August 1983.

(2) Niagara County Refuse Disposal Site

Activity: Identify parties responsible for waste disposal at the site; provide opportunity for voluntary compliance; perform CERCLA remedies if voluntary compliance is not achieved.

Status: USGS completed its survey for this site, and EPA's contractor completed the draft Remedial Action Master Plan (RAMP). EPA has reviewed the draft and provided comments to the contractor.

Next Steps: The RAMP is expected to be completed in April 1983. EPA has requested its contractor to conduct surface water and sediment sampling as well as a hydrogeological investigation. This work will be scheduled in the next few months. Negotiations are continuing between EPA and DEC in the event that Superfund monies are used for remedial action.

C. Issuance of RCRA Permits for Active Treatment, Storage, or Disposal Facilities

Activity: RCRA Part B applications must be completed by facilities which treat, store or dispose of hazardous wastes, before RCRA permits can be issued by EPA. There are 17 facilities located in the Niagara Frontier which are currently under active consideration for priority permit issuance. Two facilities have been dropped from active consideration for reasons given in the attached table.

Status: Part B applications have already been requested for 14 of the 17 facilities which are under active consideration for priority permit issuance. Eight of these 14 facilities manage hazardous waste exclusively in tanks, containers and/or piles. Four utilize incinerators to manage hazardous waste, while two dispose of hazardous waste in landfills. The Part B requests for the two landfill facilities were made on February 4, 1983, shortly after the regulations establishing permit standards for land disposal facilities took effect.

Next Step: See Attachment II for the planned schedule (revised) of permit development for these facilities.

D. Industrial Groundwater Monitoring

Activity: Monitoring of Groundwater at Industrial Plant Sites

Status and Next Steps: In December 1982, Camp, Dresser and McKee, a consultant for the City of Niagara Falls, completed a preliminary report describing debris and sediment obstructions in the Falls Street Tunnel. Sediment and groundwater infiltration samples were analyzed, and the data were presented in the report. EPA, DEC and the contractor have agreed that additional sampling and analysis of groundwater and sediment is appropriate to provide a more comprehensive chemical characterizaton of infiltration waters. This additional sampling and analysis should be completed within the next few months.

DEC has already received monitoring data from several industrial facilities. Three facilities are conducting groundwater monitoring pursuant to DEC and RCRA regulations. DEC is incorporating groundwater monitoring requirements into SPDES permits where appropriate. EPA/DEC will review this information together with data available from other sources such as the USGS study and the Falls Street Tunnel study to continue the process of identification of the nature and extent of groundwater contamination problems and the appropriate tools for resolving any such problems.

E. Hyde Park Progress

Occidental Chemical Corporation was able to continue the installation of monitoring wells throughout the winter due to unexpectedly mild weather. Work continues on the definition of the extent of chemical migration from the landfill in order to develop the appropriate remedial measures.

V. Evaluation and Control of Non-Point Source Contamination

Project Leader: Vacys Saulys, Great Lakes National Program Office (GLNPO)

A. Contaminated Groundwater

Activity: The USGS is to survey 76 sites identified by DEC (and reviewed by EPA); compile and review available information on 82 additional sites from EPA and DEC files and describe the hydrogeology of these sub-areas of the Niagara Frontier: (a) Lackawanna to Buffalo, (b) Tonawanda-North Tonawanda, and (c) North Tonawanda-Lewiston.

Status and Next Steps: All originally scheduled fieldwork has been concluded. This includes:

1. Installation and sampling of all sub-area wells for the hydrogeological studies.

2. Installation of wells and sampling of soil and water (where available) at 76 landfill sites.

3. Collection and review of all historical, hydrogeological, and analytical information for 82 additional landfill sites.

4. Electromagnetic studies at 13 selected sites to determine potential plumes of migration of chemical contaminants.

5. Installation of wells and sampling at selected U.S. Army, Corps of Engineers dredge spoil disposal sites.

The above work entailed the sinking of 72 wells and the collection of 396 water and soil samples.

Due to previously identified sample shelf life and detection level problems, it has been decided to resample soil at thirty of the 76 landfills. USGS will use the same drilling crew to collect these samples starting mid-May, 1983. We expect to receive the analytical data in August 1983. The USGS report will be finalized shortly after receipt of this data, i.e., approximately September 1983.

B. Lake Erie Dredge Spoil Survey

Activity: EPA, in cooperation with DEC, conducted a survey at the site of an open dredge spoil disposal area in Lake Erie which was utilized until confined disposal sites were available in 1973. EPA field work was conducted in June 1982 and supplemented in September 1982 as a result of the preliminary information obtained in June. Since the last report, EPA authorized USGS to conduct a drilling and sampling program at three confined disposal sites. At one of these sites, surface water levels will be monitored to determine the permeability of the site and the consequent potential for the migration of contaminants through the rip-rap wall on the lakefront face of the site.

Status and Next Steps: Since the last report, the drilling at the confined disposal sites has been completed. The contractor laboratory is now analyzing the results and should complete its analysis within the next month. The draft report on the open lake disposal sites was completed February 1, 1983 (as scheduled). EPA staff is reviewing the findings and will issue a final report in the next few months. Then the Lake Erie Survey activity will have been completed with the exception of the surface water level monitoring program which will continue through the Fall of 1983.

C. Other Non-Point Source Evaluation

Activity: EPA is conducting a review of existing literature/data on combined sewers. DEC has conducted a storm sewer survey to identify illegal hookups and contaminants in approximately 40 storm sewers along the Niagara River.

Status and Next Steps: Peer review by DEC and EPA of the GLNPO contractor report of existing information concerning loadings of phosphorous and other contaminants from combined sewer systems in the Buffalo area raised several issues that needed to be addressed. These comments are being incorporated, and the final report should be available in the next few weeks. DEC Region 9 expects to complete the report of its laboratory analyses and survey results within the next few months.

VI. Reevaluation of Monitoring Programs for Public Water Supplies

Project Leader: Victor J. Kimm, Office of Drinking Water

Activity: EPA, in cooperation with the New York State Department of Health (DOH), will evaluate the extent of contamination of drinking water utilities along the Niagara River and recommend changes to existing monitoring programs, as necessary.

Status: New data received by the Office of Drinking Water (ODW) include: monitoring by the City of Niagara Falls for indicator compounds and 40-50 volatile organics (May 1982 - December 1982); monitoring by the Ontario Ministry of Environment (MOE) at Niagara Falls, Ontario and Niagara on the Lake for organic compounds (October 1981 - June 1982); and a draft summary report, prepared for the Niagara River Toxics Committee by the State University College at Buffalo, evaluating the presence of toxic chemicals in the Niagara River. Anticipated data still to be received and analyzed by ODW include monitoring by MOE of metals and pesticides at different river ranges (near municipal drinking water intake points), and a summary report by DEC on point and non-point source toxic inputs to the Niagara River.

Recent monitoring (May 1982 - December 1982) at the City of Niagara Falls indicate increased concentrations of chemicals occurring within the main raw water intake structure (apparently leaching from the nearby "S" hazardous waste site). As a result of this the City, through cooperation with the DOH, has decided to close the main intake line as early in 1983 as possible and draw all needed water from the secondary intake line that appears to be free from contamination. An acceptable protocol during and after this change is now being determined by the City and DOH. The quality of the finished water remains high and chemical concentrations are at levels sufficiently low as to present no significant health risk from consumption of finished water.

Next Steps: A final report will be submitted to the Administrator in April 1983. All ten public drinking water supplies in the Niagara Frontier will be evaluated on a case-by-case basis.

ATTACHMENT I

STATUS OF PERMIT ACTIONS - MAJOR NIAGARA FRONTIER SPDES INDUSTRIAL PERMITS

	Final Permit Issued	Permit Number
1.	Allied Chemical Corp.	NY0002160
2.	Buffalo Color Corp.	NY0002470
3.	Dresser Industries, Inc.	NY0001996
4.	F&M Schaefer Brewery Corp.	NY0102318
5.	Niagara Mohawk Power Corp.	NY0001023
6.	NL Industries, Inc.	NY0000230
7.	P.V.S. Chemicals	NY0011043
8.	Westinghouse Electric Corp.	NY0001210
	Facilities Closed or Operations Curtailed*	
1.	Bethlehem Steel Corp.	NY0001368
2.	National Steel Corp. (Hanna Furnace)	NY0001597
3.	Republic Steel Corp.	NY0001881
4.	Donner-Hanna Coke	NY0003310
5.	Shenango, Inc.	NY0083267
	Public Comments Under Review	
1.	E.I. duPont de Nemours & Co., Inc.	NY0003328
2.	Olin Corp.	NY0001635
3.	Tonawanda Coke	NY0002399
4.	GM Corp., Chevrolet Motor Div.	NY0000574
	Draft Permits Being Developed	
1.	Occidental Chemical Corp. (formerly Hooker Chemical) - Niagara Falls	NY0003336
2.	Occidental Chemical Corp. - Durez	NY0001198

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* Need for permit issuance being assessed.

ATTACHMENT II

Schedule for RCRA Permit Issuance to Priority Facilities

Name	Part B Requested	Part B Submitted	Draft Permit
Olin Corporation (3)	2/24/82	8/31/82	4/83
Frontenac Environmental Services	4/6/82	(1)	(1)
GMC, Chevrolet (Buffalo)	2/24/82	9/1/82	(2)
Hooker Chemical (Niagara Falls) (4)	9/9/82	3/83	8/83
Hooker Chemical (N. Tonawanda) (4)	10/29/82	4/83	10/83
Reichold Chemicals (4)	10/29/82	4/83	10/83
Battery Disposal Technology (4)	9/9/82	3/83	9/83
Frontier Chemical Waste (3)	9/9/82	3/83	6/83
Krolab Products (3)	9/9/82	3/83	5/83
Resource Recovery (3)	10/29/82	4/83	8/83
Pratt & Lambert (3)	9/9/82	3/83	6/83
Voelker Analysis (3)	11/19/82	5/83	8/83
Allied Corporation (3)	9/9/82	3/83	5/83
Love Canal Leachate Treatment Plant (3)	11/19/82	5/83	8/83
SCA Chemical Waste Services (5)	2/4/83	8/83	2/84
Cecos International, Inc. (5)	2/4/83	8/83	2/84
Bethlehem Steel (5)	3/83	9/83	3/84
Chemical Leaman Tanks Lines (5)	3/83	9/83	3/84
Bell Test Center (4)(5)	3/83	9/83	3/84

(1) Applicant does not plan to conduct activities requiring a permit. Therefore, no permit will be issued.

(2) Part B application indicates that the applicant does not plan to conduct activities requiring a permit. Therefore, no permit will be issued.

(3) Tank, container and/or pile facility.

(4) Incinerator facility.

(5) Landfill and/or surface impoundment facility.

IV. Hazardous Waste Disposal Site Initiatives

Project Leader: Conrad Simon, Region II

A. Inactive Site Survey

Activity: EPA and DEC will assemble the technical and legal information required to: (1) support a voluntary compliance/Resource Conservation and Recovery Act (RCRA) §3013/Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) §106 program to assess potential hazards presented by inactive hazardous waste sites in the Niagara Frontier, (2) perform additional monitoring where necessary, and (3) establish priorities for remedial actions as required.

Status: The U.S. Geological Survey (USGS) completed its sampling at all 76 sites scheduled for study. (Originally sampling was scheduled for 73 sites. Five additional sites were added to the list, and two sites for which adequate preliminary data existed from other sources were deleted from the list for an overall total of 76.) EPA, USGS and New York State scientists met in January 1983 to assess the status of the project. As a result of concerns about the quality of data due to problems with sample shelf life and detection levels, a decision was reached to recollect soil and sediment samples at 30 sites. Approximately 30 water samples were also recollected and analyzed by EPA contractor laboratories. The results of the analyses of these water samples have been transmitted to USGS for inclusion in its study. Since essentially all work has been completed, the study work plan will no longer be included with the progress reports on the Niagara Agenda.

Data collected by USGS indicated significant chemical contamination in samples taken from groundwater wells installed near the Robert Moses Parkway in the vicinity of the DuPont plant. The DEC has initiated negotiations with DuPont officials to develop a monitoring program that will provide sufficient information to determine the nature and extent of any necessary remedial program to address this contamination. EPA will assist DEC in the review of any technical submissions to be made by DuPont and in the development of any monitoring or remedial programs.

Next Steps: EPA/DEC will continue to collect their own data and utilize data collected by USGS to assist in the ongoing process of preliminary assessments, field investigations and evaluations (with the hazard ranking system) of sites for inclusion on the national priorities list (NPL) for potential CERCLA action pursuant to §106 (administrative orders or court action for injunctive relief) or §109 (use of the Superfund, if identified responsible parties are unable or unwilling to undertake necessary remedial actions).

B. Expedite Superfund Actions

(1) Love Canal

Activity: Implementation of Superfund Remedial Actions

Status: Sevenson Construction, Inc. has completed construction activities which were necessary for the preparation of the site for the installation of

WORST CASE ANALYSIS

Question: Perhaps the most controversial activity of CEQ during the Reagan Administration was issuance of draft guidance on so-called "worst case analysis". What happened after these regulations were withdrawn?

(Follow-up if regulations issued:)

How were these regulations received by the environmental community?

Answer: In August, 1983, the Council published draft guidance in the Federal Register (48 Fed. Reg. 36486) concerning the worst case analysis requirement (40 CFR 1502.22). The Council solicited comments on the draft guidance and received a total of 64 comments. After analysis of the comments, the Council withdrew the proposed guidance. (49 Fed. Reg. 4803 (1984)).

Examination of this regulation continued to be a priority of the Council after the withdrawal of the proposed guidance. On December 31, 1984, the Council published an Advance Notice of Proposed Rulemaking. The ANPRM stated that the Council was considering the need to amend the regulation, and that to assist in its review, the Council wished to solicit written comments from all interested parties to five questions in the ANPRM. (See Appendix F of the CEQ Budget Request.) The Council received a total of 161 comments: 68 from business and industry, 33 from public interest groups, 23 from Federal agencies, 19 from individuals, 16 from State governments, and two from Congressional and legislative groups.

On March 18, 1985, the Council met "in the Sunshine" for a briefing session on these comments. Subsequently, the Council determined to proceed with an amendment of the regulation. As of this date, the General Counsel has been meeting with each of the Members and will draw up a formulation that reflects their views. Once a final draft is prepared, the Council will enter into rulemaking.

GROUNDWATER CONTAMINATION BY PESTICIDES

Question: Last year you mentioned a workshop you planned to hold on groundwater contamination by pesticides. I am very interested in this subject because Wisconsin has a serious pesticide contamination problem. Was the workshop ever held, and if so what did you learn from it? Did you make any recommendations as to the need for a nationwide groundwater strategy?

Answer: Funding was not available for a workshop on pesticide contamination of groundwater. However, the Council is currently participating with EPA in two joint studies on the pollution of groundwater by pesticides. One study examines the extent to which groundwater contamination by pesticides occurs from both agricultural and non-agricultural uses. This is one of the first times a government study will examine ways to reduce non-agricultural groundwater contamination from pesticides. The second study will develop options for protection of vulnerable groundwater resources through revised pesticide labelling. The final reports from both of these studies are expected to be completed in December, 1985.

While CEQ has not made any recommendations for a national strategy, it has recently completed Congressionally-mandated feasibility studies for a national water research center and a national water information clearinghouse. The studies presented and evaluated several different options, which are set forth in Appendix C of the CEQ Budget Request. The results were transmitted to the Congress for evaluation. Lastly, EPA has undertaken its own effort to develop a national groundwater protection strategy.

QUESTIONS SUBMITTED BY SENATOR LEAHY

NEPA/WORST CASE ANALYSIS

Question: On page 6 of your justification, you list as a major accomplishment your work on a "NEPA study of worst case analysis."

You have issued an advance notice of rulemaking in this area. I understand your final decision in this rulemaking is due soon.

This new regulation weakens the requirement under NEPA for an agency to look at possible, but unlikely, catastrophic accidents. If this new NEPA guidance is adopted, and the Bhopal facility were a U.S. facility, would it have to consider the possibility of the type of accident that occurred there?

Answer: The Advance Notice of Proposed Rulemaking (ANPRM) regarding 40 C.F.R. 1502.22 (the regulation containing the "worst case analysis" requirement) did not contain a proposed amendment to the current regulation. Rather, the ANPRM stated that the Council was considering the need to amend the regulation, and that to assist in its review, the Council wished to solicit written comments from all interested parties to five questions included in the ANPRM. (See Appendix F of CEQ's budget request.)

The comment period for written reponses to the ANPRM was extended until February 15, 1985. We received 161 comments in response to the notice. A summary of those comments is attached. On March 18, 1985, the Council met "in the Sunshine" for a briefing session on these comments. Subsequently the Council determined to proceed with an amendment of the regulation. As of this date, the General Counsel has been meeting with each of the Members and will draw up a formulation that reflects their views. Once a final draft is prepared, the Council will enter into formal rulemaking.

COMMENTS RECEIVED IN RESPONSE TO THE ADVANCE NOTICE
OF PROPOSED RULEMAKING - 40 C.F.R. 1502.22

49 Federal Register 50744
December 31, 1984

State Governments:

1. Thomas Irvin, Commissioner, Department of Agriculture, State of Georgia. "This rule addresses the exception. . . . In such cases, it is most essential that scientific uncertainties or information gaps be identified and. . . evaluated to the 'most reasonable extent possible.' Forecasting of environmental effects in the presence of scientific uncertainties or information gaps, however, should and must not be based on 'worst case analysis', since theoretical conditions used for such analyses may be ridiculously far beyond any conditions which might reasonably be expected to occur. Most often, in cases where scientific uncertainties would not permit a structured analysis, such uncertainities would also mitigate against use of a worst case analysis.

   "Under the above circumstances consideration should be given to use of the term 'highly probably adverse effects case'. . . . This term could be defined as a 'set of projected, theoretical circumstances or conditions, which would reasonably be expected to occur, and based upon limited scientific information and/or the consensus of recognized scientists in the applicable field, there exists a more than even probabiity that adverse environmental effects may occur."

2. M. Keith Ellis, Director, Department of Agriculture, State of Washington. Recognization of data gaps is more important than creating scenarios limited only by imagination.
   (1) Worst case analysis should be done (a) when there is evidence to support the belief that the hazard exists; (b) when the exposure history is so meager that logical solutions cannot be drawn from experience or existing data, and (c) when the federal use is likely to result in significant additional exposure beyond what is being experienced with existing use of the chemical.
   (3) The rule of reason must apply and rational standards must be established.

3. William Webster, Attorney General, Robert Lindholm, Assistant Attorney General, State of Missouri. "Your existing rule is a good one . . . and it should be retained."
   (1) Federal agencies should engage in forecasting when there is the potential for a significant adverse effect on the human environment, and depending upon the degree of that impact, the agency should be required to engage in their best possible judgment of future consequences of their proposed action.
   (2) The analyses should be objective and incorporate insofar as possible information sources outside of the agency with no direct interest in the project.
   (3) Application of the rule of reason should result in adequate analyses in any situation involving potential impacts which could be injurious to significant numbers of human beings, or the resources which sustain them in life.
   (4) The threshold is already described in large measure by the existing regulation. "Whenever it appears that our actions could endanger life or the supporting environment, it should be the subject of thorough investigation."
   (5) The term "worst case" should be retained and defined as the set of adverse impacts that are reasonably foreseeable employing known information and informed judgment applying objective standards.

4. Don Ahrenholtz, Executive V.P., Washington State Farm Bureau.
   (5) "Worst case" has a very negative connotation; "expected results" would be more appealing to our members. This should be defined to mean,

if the proposed action were taken under the rules develpped for use of the product, what environmental impact would be expected. "We don't believe the Council should be expected to forecast or speculate about the unknown."

5. J. C. Kraft, Florida Department of Transportation. Believe that the regulation is appropriate as it stands, based upon our experience in developing transportation projects where occasinally uncertainty occurs on an environmental issue. The process of exploring uncertainty can lead to mitigation plans and monitoring for unanticipated changes. The regulation should not be changed.

6. Neil Pedersen, Maryland Department of Transportation.
(1) Two examples of agency speculation are forecasting pollutant loading impacts associated w/high run-off on water quality and predicting effects upon businesses when bypasses are considered. The agency should forecast the worst case impacts to determine the level of effect of a prposed action.
(2) An analysis which presents reasonable forecasting should:
---describe the potential impacts of the project;
---determine the probability of the impact occurring vs. the severity of the impact;
---identify possible mitgation based on the available scientific information.
(3) No, the regulation does not go beyond the rule of reason.
(4) Yes, a threshold would be good (no suggestion as to which one).
(5) "Worst case" is an appropriate term. Any worst case defintion must taken into account the probability of an impact occurring. The agencies involved in reviewing a proposed action should arrive at a consensus of opinion regarding variables which contribute to worst case impacts.

7. Art Stearns, Department of Natural Resource, State of Washington.
(1) Agencies should engage in forecasting or speculation when making decisions on major projects and programs which wil have substantial long-term consequences. There should be a rule of reason governing the extent of speculation, and such speculation should be within the bounds of accepted scientific findings concerning the impacts in question. In other words, the analysis should proceed from what is known towards what is not known, rather than leaping to speculations about which there is no basis for judgment. The analysis should evaluate risks from range of situations.
(2) Understandable information for decision-makers and other interested parties can best be provided if the analysis includes probabiities of adverse effects in comparision w/probabilities of similar effects resulting from actions familiar with people's everyday experience and w/probabiities of simillar effects resulting from other common government decisions... The analysis should also seek to identify which factors are most responsible for the forecasted risks so as to allow decision-makers to evaluate their abiity to take feasible actions to reduce risks.
(3) The existing rule does require agencies to go beyond the rule of reason. The Washington state SEPA rules require that, "If the agency proceeds [in the face of uncertainty] it shall generally indicate . . . its worst case analysis and the likelihood of occurrence, to the extent this information can reasonably be developed."(emphasis added in letter). This wording is preferable to the federal regulation.
(4) It is very important to establish a proper threshold to give some explicit guidance. It would be preferable to refer to situations in which there are substantial gaps in scientific information, where reasonable inferences are not possible, or significant dispute exists among qualified scientists in published literature, and the information that is absent or in dispute is essential and a reasoned choice among alternatives cannot be made by inference from existing information or judgment as to the scientific dispute.
(5) The term worst case may or may not be appropriate, but a number of other terms are prevalent in scientific literature that may be better.

Other comments: The Department of Natural Resources is undertaking a worst case analysis of the impacts of aerial spraying of herbicies on state-owned forest land. We have an MOU with the federal EPA for doing this, and are also coordinating with the U.S. Forest Service. We commend CEQ for its efforts to reevaluate this rule, because we believe that although the worst case requirement was well-intentioned and reasonable in principal, it may have become a vehicle for paralysis. rather than better decisions. We do not think this was CEQ's intent.

8. E. S. Hunter, Department of Transportation, State of Oregon.
(1) Forecasting and speculatin should only be done when the techniques used are generally avccepted within the scientific community. Forecasting should only be done when the results are predictable within a reasonable degree of statistical probability. We would discourage speculation in defining probable environmental effects.
(2) Agreement on analysis is unlikely to occur in the face of scientific disagreement, when this analysis is required. A better approach is to use accepted or at least defensible methodologies and let disagreement speak for itself.
(3) No, one can't go beyond the rule of reason.
(4) Thresholds are inappropraite - they are subjective and impossible to apply uniformly.
(5) "Worst case" is appropriate, as it gives decision-makers and the public a sense of abolute magnitude. It should be defined as the outcome produced from the combination of assumptions using accepted methodologies that produces the most probable event. This result can then be contrasted with the probability of the least probable event, giving reviewers a comparision for decision-making purposes.

9. Keith Buttleman, Council on the Environment, Commonwealth of Virginia.
(1) The circumstances under which an agency should consider the use of forecast information should be determined by the degree of possible environmental damage which may result from a given action, the extent to which forecasting can produce a plausible result, and the probability of the damage. An agency should not speculate beyond what is reasonably forecast.
(2) A range of scenarios and analyses should be provided. Assumptions should be stated and their reasonableness made subject to evaluation. Use of models, hypothesis testing and monitoring may be appropriate.
(3) The regulation does not require agencies to go beyond the rule of reason.
(4) The regulation's inherent threshold seems to be sufficient as a threshold for forecasting. The regulation does not, in our judgment, require speculation.
(5) "Contingency analysis" might be a better term than "worst case"; however, worst case has fairly common usage and is both suitable and concise.

Other comments: We believe the regulation should stand as it is. (Note: this letter assumes August, 1983 guidance was finalized). The regulation plus guidance is useful and a change to the regulation could result in the taking of an action without serious consideration of its rasonably forseeable adverse impacts.

10. David Blabey, Department of Public Service, State of New York.
It is has beenour experience that when worst case analyses are included in assessment, they are publicly interpreted to be what is likely to occur despite analysis that shows they are very unlikely events. Therefore, to put the worst case in perspective, we suggest amending the last sentence of the regulation to read, "If the agency proceeds, it shall include an analysis of the expected range of possible results, its estimate of the most likely results and a worst analysis [and] of the effects of the unavailable information as well as an indication of its estimate of the probability or the improbability of [its] the occurrence of each of the scenarios analyzed."

11. Donald Adams, Department of Transportation, Highway Division, State of Oregon.
We want to encourage you to proceed with rule makng that will return the rule of reason to the decision-making process in determining when a worst case analysis is needed for an environmental impact statement. The current court injunctions against the use of herbicides on Bureau of Land Management and Forest Service lands are jeopardizing our ability to maintain highways across these federal lands in a safe and economical manner. We are now being forced to use more costly mechanical and hand methods for controlling weeds and brush for safety and drainage purposes. Additional costs for using these alternative methods will be will in excess of $100,000 the first year and will increase in future years.

12. Janice Corr, Deputy Commissioner/General Counsel, New York State Department of Environmental Conservation.

(1) A federal agency should engage in a worst case analysis under the circumstances currently prescribed in the regulation. The regulation should continue to require a low threshold for triggering this requirement.

(2) The regulation, as interpreted by the courts, requires "reasonable speculation" on the potential adverse impact of a project. Agencies should continue to apply the catastrophic case analysis, including an assessment of the probability of occurrence in reaching their conclusions.

(3) The rule of reason has been applied to this as well as other CEQ regulations; there is no reason to depart from this precedent.

(4) There is no basis to depart from the current threshold for requiring a worst case analysis.

(5) There is no reason to change the term "worst case".

Other comments: The New York State Department of Environmental Conservation strongly recommends continuation of the current worst case analysis requirement. Consideration of the worst case analysis is consistent with the policy underlying NEPA and can be integral aspect of the decision-making process if reasonably applied.

13. Timothy Patterson, Deputy Attorney General, Department of Justice, State of California.

(1) Agencies must evaluate environmental impacts with low probabilities of occurrence but with substantial catstrophic effects. It is our view that the principle of full disclosure mandates such review and, further, that federal agencies are capable of undertaking such review.

(2) and (3) The existing worst case regulation can be implemented effectively without abandoning the rule of reason. Reasonable projections of the worst possible consequences of a proposed action are productive, valuable guideposts to informed environmental decisions. The present regulation and existing case law do not promote unreasonable speculation. We believe no amendment is necessary for the regulation to abide by the rule of reason.

(4) Formulating a unviersally applicable standard for triggering a worst case analysis tends to defeat the basic purpose of such analysis: forcing an agency to examine the most dire environmental consequences of a proposed action if it wishes to proceed with the project in the very limited situations outlined in the current regulation. Thresholds, by definition, limit the universe of consequences to be identified and reviewed. Such limitations are inconsistent with the need for an agency to deal as best it can with proposed actions in the face of uncertainty.

(5) "Worst case" is a vivid term, and therein lies its usefulness in the NEPA full disclosure process. It is appropriate for focusing attention on the perils of proceeding in the face of uncertainty. Because the term effectuates the goals of the current regulation, it should be retained.

14. James Larocca, State of New York Department of Transportation.

(1) Since we seldom know everything about anything, there are almost always gaps in information or uncertainties concerning the environmental effects of a proposed project. This situation can be used by opponents of projects to stop and delay actions. In most cases, additional study does little to resolve basic objections. There is a real need for some method of decision making in the face of uncertainty.

(2) The most useful and reasonable way to proceed is to formulate a potential range of impacts from optimistic to pessimistic, or more appropriately, from favorable to unfavorable. A serious attempt should be made to study possible outcomes at both ends, with a range of probable impacts in between the two extremes.

(3) The worst case analysis requirement goes beyond the rule of reason and invites speculation of the type which the courts previously said was not required in EIS(s).

(4) A general threshold or guideline should be established by CEQ. For example, when human health or endangered species might be threatened, an analysis which quantifies a range of potential impacts is warranted.

(5) There appears to be difficulty understanding what is meant by a "worst case analysis"; it appears to distress and polarize various groups. We recommend that when information relative to adverse impacts is not known, either because it is too expensive to obtain or because the means for obtaining it are not known, that agencies be required to define a reasonable range of impacts from favorable to unfavorable.

15. Denise Fort, Environmental Improvement Division, State of New Mexico.
We are not convinced that there is a strong need to amend the regulation, although guidance from CEQ may be in order. We urge that CEQ action provide a strenghtened ability to the affected public to insist on full disclosure in the EIS process.

Worst case analysis should be required whenever it may reveal information useful in reaching a reasonable final decision about a project. To this end, we recommend some type of threshold system for determining the need for a worst case analysis. "Probability of occurrence" and "severity of consequences" should be the primary triggers.

16. Gordon Van Vleck, The Resources Agency of California.
(1) Speculation and unfounded forecasting by an agency confronted with scientific or information uncertainty can only be condoned in those situations amounting to a crisis. Only events of cataclysmic effect on the environment would justify more than short-term remedial or preservative action.
(2) Risk analysis is available as a method for measuring the effects and consequences of various solutions to a given problem. It is doubtful that anyone could analyze a "worst case", since by its very definition in the regulation, information is unavailable on which to base the analysis.
(3) The regulation goes beyond the rule of reason by requiring a a worst case analysis when there is any degree of uncertainty or perceived gap in information.
(4) Thresholds should be established which would identify the level at which a decision or action should be triggered. The thresholds suggested in the ANPRM require considerable refinement and more precision to appropriately establish an action level.
(5) The term "worst case" is inappropriate. Among other problems, it is undefinable. "Risk analysis" should be used instead.

Comments from Business and Industry:

1. John T. Barr, Manager, Regulatory Response, Air Products and Chemicals, Inc.:
There will always be uncertainty and missing information which could possibly relate to a proposal. The problem with the worst case analysis has been that agencies rely largely on that one case for deciding whether a project is unacceptable. "If we were writing 1502.22, we would restate it to acknowledge the fact of missing data in all cases, and write the paragraph with declarative, transitive verbs that anticipate an ongoing process. In particular, we would would change the last sentence to something to this effect: 'As the agency proceeds, it shall evaluate a range of scenarios along with the probability of their occurrence, but shall base its decision on a reasoned judgment of the most likely outcome of the proposed action.'

2. Andy Lukes, Planning Manager, Champion International Corporation.
(1) When an action generates a reasonable probability that significant environmental impacts (both adverse or beneficial) may occur, such consequences should be acknowledged in the EIS. Speculation without scientific support of significnat impact should not be included if a reasonable man would not consider this information sufficient to not carry out the proposed action.
(2) The key target must remain the decisionmaker's needs.
(3) Yes. I would suggest the occurrence of probabiity as one chance in ten as this probability level reasonably defines the chance of "likely" or "nor likely" to occur.
(4) Yes.
(5) Suggest use of term "low probability negative outcome case" instead of "worst case".

3. Richard White, Manager, Environmental Services, Texas Utilities Generating Company.
(1) Only effects which have a reasonable probability of occurring and of having a significant effect on the environment need to be addressed in the EIS. If data are not available to accurately address these effects, predictions would be required. If effects have low probabiity of occurring and a low probability of causing a significnat effect on the environment, they do not need to be addressed.

(2) The problem is having to address effects having low probability of occurring or having a low probability of being significant. For high probability occurrence or effects, the effects need to be addressed and missing data either acquired or the EIS must state that the significance of the potential effects it not known.
(3) If regulatory agencies followed the intent of 1502.22, they would not go beyond the rule of reason.
(4) Yes, a threshold standard should be used of high probability of occurrence and significance.
(5) "Worst case" is not appropriate. A better term would be "projected" or "forecast" analysis. "In essence, a projected/forecast analysis is required when data are not available to evaluate a significant adverse effect."

4. Frank Favor, DAW Forest Products Company. "We believe that [the regulation] should be withdrawn and rewritten. We believe that new guidelines should be drawn as to when it should be used, life threatening situations only. Also, you should remove ambiguities from the guidelines, such as "are not exorbitant", "probability or improbability of its occurrence", "threshold standard" and others."

5. Chris Whipple, Electric Power Research Institute (EPRI). Recommend that th last sentence of 1502.22(b) be deleted and that "worst case" not be used in any form in future regulation. "Worst case" distorts regulatory attention, causes misapplication of resources and is counterproductive to public safety.
   (1) When adverse effects cannot be plausibly forseen, because of the absence of a reasonable scientific basis, public safety is best assured by a risk management approach which is designed to contain and mitigate the adverse effects as they arise.
   (2) When an empirical experience base is not available, Probabilistic Risk Assessment, as provided in NRC analysis, is an excellent model. They represent the best professional judgment and guide regulatory emphasis in precautionary risk management policies.
   (3) The rule of reason should be reflected in a revised regulation
   (4) It is not feasible or useful to establish a threshold for instituting speculative forecasting, whether it be for consequences, probabiity, or credibiity. Professional judgment should dictate the domain for action.
   (5) It is not possible to define a "worst case" and it should not be used. Suggest the term "off-design" as most descriptive and best way of describing uncertain or unforseeable effects.

   They also attached a paper entitled "Risk Uncertainty and Risk Mangement" by Chauncey Starr, EPRI. It discusses Probabiistic Risk Assessment.

6. Bradley G. Penn, Marathon Oil Company. Supports the language in the August 11, 1983 guidance to implement an initial threshold of probabiity. The use of forecasting or speculation should be limited to those areas where forseeable logical events will follow and the disucssion should be proportional to the likelihood of an event happening. Analysis should be proportional to probabiity.
   (3) In regard to the rule of reason, a set of criteria could be set up which would enable the preparer to eliminate alternatives which were not reasonable. This could be a three step process: a) establish guidelines for the selection of reasonable alternatives, e.g., alternatives which could reduce potential and unresolved conflcts; b) identify the full range of alternatives potentially consistent w/the purpose of the proposed action; c) to screen the list of alternatives and retain for further study those which might be environmentally preferable to the proposed action without resulting in an excessive economic penalty.
   (4) Yes, there should be a threshold of probability based on scientific credibility.
   (5) "Worst case" in an inappropriate phrase. For instance, if an oil company discovers oil, it is our "best case" but the worst case for some. Instead, suggests "maxium impact scenario" will better enable the EIS reader to understand the trade-offs among alternatives.

Also, if we must outline the full range of environmental impacts, we should also spend as much time on the full range of appropriate mitigation.

7. Scott Simplot, Exec. Vice President, J.R. Simplot Company. Requests that 40 C.F.R. 1502.22 be amended to better effect a rule of reason.

8. Linda M. Ruzevick, Illinois Power Company. (1) Federal agencies should not engage in forecasting or speculation when confronted with scientific uncertainty or gaps in information concerning environmental effects; it is unreasonable to predict such impacts without a basis in fact.
(2) If scientific uncertainty or information gaps exist, a worst case analysis should not be required.
(3) The type of analysis in the present regulation requires federal agencies to go beyond the rule of reason. The rule of reason should be incorporated into the regulation.
(4) A threshold of reasonably forseeable impacts should be incorporated into the regulation.
(5) "Worst case analysis" is inappropriate and a term such as "probable risk assessment" would be appropriate for environmental analysis that focuses only on adverse impacts which are reasonably foreseeable.

9. Wayne Ludeman, Inland Forest Resource Council. "We support the basic concept underlying 40 C..R. 1502.22 that land management decisions must consider the potential adverse impacts of decisions made in the face of inadequate or unavailable information . . . . The primary difficulty . . . involves defining a reasonable limit on how far agencies have to go in their analysis of potential 'worst cases'".
(1) "We believe that NEPA documents should include a clear disclosure of the responsible managers best estimate of the potential adverse impacts of management decisions, the likelihood of their occurrence, and the limitations of the data used to develop these estimates. . . . As long as the NEPA documents display the managers best estimate of potentially significant environmental effects, and the limitations of the data used in the decision making process, we believe that the intent of NEPA has been served. Creation of reams of specific regulations governing 'circumstances' and 'extent' will, in our opinion, merely provide grounds for special interest groups to challenge decisions they don't like in the courts."
(2) CEQ should not mandate a specific analytical process. The decision about what type of analysis to use should be left to the professional land managers.
(3). "[W]e believe that specific regulations or analytical procedures imposed by CEQ have the potential to excessively limit professional judgment needed to make 'reasoned choices'".
(4) "We are concerned that arbitrary threshold standards imposed by CEQ regulation, no matter how carefully preconceived, will impose greater risk of misjudgment and significant environmental damage than reliance on the professional experience and judgment of trained resource management professionals."
(5) "Worst case" is inherently undefinable and should be dropped. Instead, the decisionmaker should clearly disclose his best estimate of the risk of potentially significant environmental impacts, along with the uncertainity of the information available.

If the regulations must include worst case analysis, we believe they should also require a description of the worst possible adverse envionmental consequences of a decision to take no action.

10. Michael Truax, Simpson Timber Company.
(1) When there is indisputable evidence that a significant adverse effect has occurred in the past, under an unusual set of circumstances and those circumstances could be repeated under the proposed action, or, when there is widespread belief by those scientists who have research-based expertise concerning the effects in question that a significant adverse environmental effect could occur in the future, given an unusual set of circumstances which could be present under the proposed action.
(2) In the circumstances described above, the agency should be required to estimate the probability of such impacts occurring based on consideration of historic occurrence, likelihood of similar circumstances and anticipated mitgating measures and safeguards. The environmental probability must be related to the magnitude of the potential impacts.

(3) The rule of reason must apply to agency analyses.
(4) A threshold standard should be established for evaluating significant but unlikely adverse environmental effects.
(5) "Worst case" should not be used - it, like beauty, is in the eye (or mind) of the beholder.

11. E. D. Kist, Public Service Company of New Mexico. Supports the intent of the regulation, but believes that historic variation in interpretation necessitates amendment plus guidance.
(1) Agencies must engage in forecasting or speculation where scientific uncertainty or gaps in information occur - i.e., where research is incomplete, research results are conflicting, or no research exists.
(2) Forecasting can be accomplished either by: a) use of scientifically recognized modeling/forecasting techniques and an assessment of probabiity of occurrence, or b) an assesment of existing data/research and assessment of probability of occurrence. The evaluation and modeling/forecasting should be trackable and repeatable.
(3) The regulation does not require agencies to go beyond the rule of reason but individual interpretations may vary widely.
(4) A threshold standard is not appropriate. What is appropriate is an adequate assessment of existing data w/subsequent determination of probability of occurrence.
(5) Worst case is not appropriate. Probable impact is a realistic basis for determining appropriate mitigation.

12. T.S. Ary, Kerr-McGee Corporation. "We request that 40 C.F.R. 15022.22 be amended to beter effect a rule of reason. This is especially important in view of the interpretation that the federal agencies and courts are placing upon this issue."

13. R. W. Lawhn, P.E., Houston Lighting & Power Company.
(1) An agency should engage in forecasting or speculation only in circumstances where there is reasonable expectation that significant adverse impacts wil occur which should be considered. In such cases, the speculative or forecasting analysis should not go beyond those issues to which the uncertainty or gaps in information are related, and should assume circumstances which are reasonably expected to occur.
(2) Assumptions used and the probability of occurrence should be articulated. The analysis should be a projection of environmental effects given the worst set of circumstances reasonably expected to occur simultaneously.
(3) Unfortunately, the courts have interpreted it as going beyond the rule of reason. This should not be the case, however, and the purpose of such analysis should be to provide an 'upper bound' of predictable impacts.
(4) Threshold standards would seem useful and prudent. No single standard should be established; rather, a set of standards should be established which should be met before initiating the analysis. By establishing an appropriate set of threshold standards, one could be reasonably assured that the type of analysis called for in the regulation would be performed only in those cases where significant adverse impacts are reasonably foreseeable.
(5) The analysis should be called 'worst predictable case' and not the 'worst imaginable case' as is often the interpretation of worst case analysis.

14. Richard Bratcher, Wisconsin Electric Power Company. The need for an approach other than worst case analysis has become increasingly acute recently. A rationale approach to assessing risk in the face of large uncertainty should be incorporated into the NEPA process.
(1) "Agencies and applicants almost always must undergo some form of prediction in the face of scientiic uncertainty or gaps in knowledge. The extent of speculation which should be engaged in should be extremely limited. Predictions reflecting a range of possible outcomes, along with judgments of the likelihood of such outcomes, should be prepared rather than a single 'worst case' scenario.
(2) "Techniques such as decision analysis can be employed to represent multiple possible outcomes associated with decisions and scientific uncertainty. Combined with sensity analysis, this approach holds great promsie for providing useful information to decisionmakers and interested parties."

(3) The language of the regulation lays a reasonable foundation. However, terms such as "exorbitant" and "severity of possible adverse impacts" are subject to widely divergent interpretation.. Definition of these terms could be helpful.
(4) At a minimum, scientific credibility should be mandated. Only scientifically credible scenarios with some significant probability of occurrence should be included.
(5) Worst case is an appropriate term for many analyses, except to the extent that they have been carried so far as to be virtually impossible in the real world. If the approach suggested in (2) above were followed, it would not be necessary to coin a new term. Rather, the appropriateness of analyses incorporating elements of both quantitative risk assessment and risk management would be recognized.

15. Michael Sullivan, Industrial Forestry Association. "It is our view that the current interpretation of worst case analysis by the courts goes well beyond reason and is being employed by anti-pesticide and anti-forestry groups to obstruct legitmate management without any corresponding benefits to society as a whole."(1) There are no activities which do not have scientific uncertainty or information gaps. "It seems to us that no ageency should be required to speculate on environmental impacts."
(2) We believe the fundamental issue here is to assure that decisionmakers have reviewed all relevant impacts in the process of deciding a course of action. This requires that the information procssed be of a substantive nature. Where no such agency exists and is impossible to obtain, the agency should determine the importance of the lack of information to a reasoned decision and the probabiity that the absence of that information might result in an adverse environmental impact.
(3) Yes - the Ninth Circuit opinions do go beyond the rule of reason.
(4) It is our view that any trigger for a worst case analysis should be based on the probability of an event occurring, given the best scientific understanding currently available.
(5) Worst case as a term is inappropriate. Other possibilities would be either "probable worst case" or "scientifically probable worst case analysis".

16. H. Schuyten, Chevron U.S.A. (1) We recommend that CEQ require worst case analysis only where additional unknown information is essential to a reasoned choice among alternatives and is either unknown due to unavailable means to obtain it or unknown due to exorbitant costs of obtaining it, thus eliminating the dual threshold currently in the regulation. We also recommend that the regulation be clarified to assure that the analyses address probable impacts of the proposed project alone and not of subsequent project-related events which have not been, and may never be, proposed, and that worst case analyses are required only in EIS(s) as opposed to EA(s).
(2) First, worst case analyses should only be prepared when occurrence of the adverse impact is reasonably probable. The analysis should then be governed by four factors: burden of performing the analysis, probability of occurrence, severity of consequences and scientific credibiity. "We support reasonable forecasting in the face of factual and scientific uncertainty."
(3) No - we beliee the current regulation is not intended to go beyond the rule of reason. Some courts' interpretations, however, have gone beyond the rule of reason. CEQ should clarify that the rule of reason does apply.
(4) Yes. We believe an initial threshold of reasonable probability should be met.. In determining whether an impact is reasonably probable, it is essential that mitigation measures proposed by the project proponent or suggested by the lead agency be considered. In addition, we recommend that CEQ examine a threshold standard which incorporates the severity of consequences and credibiity of data, as well as economic feasibility and project delay costs association w/preparation of worst case analysis.
(5) "Worst case" is not necessarily an inappropriate term; the threshold question is more critical. However, if a new term is desired,

we suggest "uncertainty analysis."

17. Peter McCallum, Sohio, Standard Oil Company.
(1) A proper evaluation of alternatives may require forecasting or speculation in areas where there is uncertainty or missing information. Those assumption which result in high impacts or low impacts should be identified and discussed. Under the current interpretation of the regulation, a great deal of speculation is needed.
(2)"It is inevitable that an agency will have to discuss possible catastrophic consequences of proposed actions, even where they are very unlikely to occur. The goal of the CEQ in re-examining these regulations thus should not be to eliminate such discussions, but to mold the regulations. . . " Any change to encompass reasonableness or a threshold of likeliness will tend to limit the discussion of extremely unlikely events.
(3) The current regulation has caused agencies and courts to go beyond the rule of reason.
(4) We do not belive it is necessary to establish threshold criteria. However, the agency's choice of which catastrophes to examine should be given some deference so that suits challenging agency decisions are not encouraged. Minor amendments to the regulations indicating that reasonableness is a criteria in the analysis would help this situation.
(5) The term "worst case analysis" should be changed or modified. Terms such as "hazard analysis", "risk assessment" or "likely worst case assessment" would tend to refocus EIS's on more realistic scenarios.

18. H. Mike Miller, National Association of State Foresters.
(1) The current requirement for forecasting or speculation is reasonable if CEQ clarifies who should make the analysis. We suggest that the agency most appropriate to perform a specific analysis should make the analysis for all affected agencies. For example, worst case analyses concerning herbicides should be performed by EPA for a comprehensive set of circumstances.
(2) The analyses should be structured to differentiate between risk and uncertainty. Risk should be considered a specific hazard to specific persons or resources, quanitified by statistical measures. Uncertainty is something for which a statistical probability cannot be attached. Uncertainty should be tested by two criteria: the reasonable likelihood for the outcome to cause significant adverse effects based on the context of the particular management activity, and/or alternative under analysis. For both risk and uncertainty, arrays of possible losses should be estimated w/qualitative and quantitative factors.
(3) The rule of reason should be used and well thought out to reflect congressional intent.
(4) A probabiity threshold should not be used, since the term uncertainty implies an inability to determine probability. Instead, we suggest a two-staged process: 1) if a significant loss of value, in relation to the benefits to be derived, could not reasonably be expected to occur, then the analysis should not be undertaken; 2) it should be determined that a reasonable person would use such an analysis in making choices among possible alternatives in a given situation.
(5) "Worst case" is inappropriate. "Uncertain but reasonably likely significant adverse environmental effects" would be a more appropriate term. "This type of analysis should be undertaken when there is a significant risk or reasonable likelihood of adversely affecting net public value."

19. John Hite, Exploration Ventures Company, Inc. (EXVENCO). We request that the regulation be amended to better reflect the rule of reason. We are particularly concerned that a worst case analysis allows unlimited subjective interpretation and can be used to prevent or hinder projects unnecessarily.

20. Eskil Anderson, Little Squaw Gold Mining Co. Requests that regulation be amended to effect a rule of reason.

21. Karl Mote, Northwest Mining Assocation.
(1) The agency should apply reason in forecasting or speculating. For instance, if worst case has a very low probability, the project design should not be made for protection against the speculative happening.
(2) If an event is considered possible during the life span of the proposed activity, although the worst case may be identified, it should not be used for design of the facility.
(3) No, the regulation does not go beyond the rule of reason.

(4) No, a threshold standard should not be established.
(5) "Worst case" is highly inappropriate.

22. F. H. Lightner, Pegaus Gold Corporation. We request that the regulation be amended to effect a rule of reason.

23. John Taylor, VEPCO.
(1) A federal agency should consider forecasting or speculation only when the potential adverse impact on the human environment is of obviously high probabiity and significance. Even then, the uncertainty should be strongly stated.
(4) No, thresholds tend to be inflexible.
(5) "Significant worst case reasonably and scientifically predictable" invokes the rule of reason upheld by the courts and should greatly speed up the process.

24. J. Thomas Wolfe, Baltimore Gas and Electric.
(1 & 2) Federal agencies should be required to assess existing data and to generate data which is reasonably obtainable to assess potential environmental impacts. Analysis of this data should produce forecasts which do not exceed the statistical usefulness of the data itself. Limitations on speculation utilized commonly by the practitioners of the particular science in question should be applied. Effort should be made to delineate for the decision-maker and the public where good science stops and qualitative speculation takes over.
(3) Under early NEPA case law, analyses should not go beyond the rule of reason.
(4) The most important alternative threshold set forth in the question is a threshold of scientific credibility. Establishing a regulatory trigger based on either a level of probability or level of severity of impact could not be done effectively in a manner to apply to all federal NEPA actions. The sufficiency of any NEPA analysis of potential impacts should rest on whether the agency in question used accepted scientific methods to analyze all reasonably available data and project a full range of potential outcomes within the limitations on speculation accepted by the scientific discipline involved.

25. David Nicholson, Weyerhaeuser Company.
(1) Speculation and forecasting are two different concepts. Agencies should not engage in speculation. It is not the function of governmental bodies to speculate. On controversial issues, decision-makers can and often must take into account the fact that various private parties are speculating about possible worst case scenarios. However, the EIS should make clear which fears are supported by credible scientific evidence.

Forecasting, on the other hand, is a useful tool in decision making. Forecasting implies predicting the future in ways generally accepted as valid by knowledgeable experts. It must be based upon valid data which provides a level of statical reliability, and have some basis in history and experience of knowledgeable individuals.
(2) Care must be taken to ensure that the data used in forecasts is valid, has been peer reiewed, and that there are no critical gaps in the array of information. Keys factors to considesr are careful evaluation of how serious the gaps are; consideration of how reliable the methodology used to produce the data was; and how serious the consquences of an incorret decision are.
(3) No - the rule does not go beyond the rule of reason. "If evidence points towards a predicted disaster or a disaster with substantial probability of occuring, it is only reasonable to evaluate that possibiity and see what reasonable steps can be taken to avoid or reduce the risk."
(4) The concept of threshold standards is a favorable one. However, any threshold begs for disputes over whether it has been exceeded. In some cases, the use of a threshold is inappropriate Scientific uncertainty will always be the key factor.
(5) "Worst case" is an unfortunate choice of words. ". . . it is impossible to determine whether the 'worst case' is the biggest disaster that might conceivably occur, or the smaller problems most likely to occur, or some combination reflecting the greatest combination of probability times severity, and whether the WCA is 'net' of the likely benefits of the project or of the maximum possible benefits (a 'best case analysis'), etc." The concept of environmental risk analysis should be brought forward instead. "The EIS should identify a full range of possible results of the proposed agency action, including those which

could produce irreparable harm. It should not be necessary to label some particular scenario as the 'worst case' or some other term."

26. Paul Mogensen, Gold Fields Mining Corporation. We request that the regulation be amended to better effect a rule of reason.

27. T. E. Erskine, ASARCO. I request that the regulation be amended to provide that worst case analysis be based upon a prudent rule of reason.

28. Neil Minecaster, Tenneco Mining Co. We request that the regulation be amended to better effect a rule of reason.

29. O. Jay Gatten, North American Exploration. We request that the regulation be amended to better effect a rule of reason.

30. Nandor Szombathy, Atlas Mine & Mill Supply, Inc. We request that the regulation be amended to better effect a rule of reason.

31. J.F. Gardner, Anaconda Minerals Company. We request that the regulation be amended to better effect a rule of reason.

32. Jack D. Early, National Agricultural Chemical Association.
(1) To fulfill its duties under NEPA, a federal agency faced with scientific uncertainty or information gaps concerning the potential adverse environmental effects of a proposed action must engage in "reasonable forecasting or speculation". Such forecasting or speculation entails evaluation of the "reasonably foreseeable" effects of a proposed action. Thus, agency forecasting need not consider potential adverse environmental effects that are purely hyothetical and that have no reasonable evidentiary foundation.
(2) Agencies should apply scientifically accepted risk assessment procedures in conducting an analysis of potential adverse environmental effects in the face of scientific uncertainty or information gaps. In the contexxt of regulatory and public health decisionmaking, risk assesssment is the analytic tool used to identify the relationship between exposure to hazardous substance and the magnitude of the risk. This must be differentiated from risk management. Any attempt at risk assessment to conduct a worst case analysis that does not include one of the four vital risk assessment steps is inadequate. These four steps are: a) Hazard identification; b) Dose-response assessment; c) Exposure assessment; and 4) Risk characterization. The last step brings together all the data and analyses of the first three; the "weight-of-the-evidence" and the various uncertainties are also summarized in this step. As presently practiced by regulatory agencies, risk assessments yield worst case characterizations of risk, but not with hypotheticl analysis without any evidentiary foundations. The assessments now performed involve the use of a series of assumptions, each of which is designed to yield the highest estimate of risk. The cumulative effect is to produce risk estimates that are truly worst case analyses.
(3) Under current court decisions, the regulation extends far beyond the rule of reason as traditionally employed by the courts. "While an agency should accumulate and analyze data in accordance with scientifically accepted risk assessment procedures to calculate risks where scientific uncertainty exists, it need not discuss remote and highly speculative consequences."
(4) A revised worst case analysis regulation should contain a threshold standard which is consistent with the rule of reason doctrine. The threshold of probability trigger is consistent with NEPA and the rule of reason. Worst case analysis should not be required for improbable, remote or highy speculative consequences, or for potential adverse impacts for which there is an insufficient evidentiary basis for determining their probability of occurrence.
(5) The term "worst case analysis" is wholly inappropriate; it intimates that an agency must focus upon the most drastic, remote and speculative of consequences and is contrary to the traditional judicial interpretation of NEPA. The term should be revised to be "environmental risk assessment", defined as the procedure by which an agency evaluates the reasonably forseeable adverse environmental consequences of a proposed action on the

basis of known or reasonably obtainable scientific data.

Other comments: an agency should be able to rely on another agency's risk assessment; for example, EPA's risk assessments prepared in accordance with FIFRA. Also, we support the Pacific Legal Foundation's petition.

33. Richard Worsfold, American Copper & Nickel Company, Inc. We request that the regulation be amended to better effect a rule of reason.

34. Jack Cearley, Conoco, Inc.
(1) A worst case analysis should be limited to reasonably forseeable events, and forecasting should have a basis in credible scientific evidence, rather than consequences that are purely hypothetical or conjectural. Specific quidance should be given to federal agencies to better determine what constitutes "scientific uncertainty and data gaps in information." While site specific data which is relevant to a decision is not available, consideration should be given to the establishment of a task force of technical experts to prepare a reasonable estimate of existing conditions. Their report should be publicly scrutinized prior to giving it to an impact assessment team. The impact assessment itself should rely on existing examples of activities similar to the proposed action, and industry should be called upon to provide reasonable development scenarios. Economically viable mitigation concepts should be considered in the impact assessment; however, reclamation, rehabilitation, etc., should be based on current examples and not on worst case assumptions.
(2) The analysis should be structured around the following: best available information with opportunity for input from all interested parties; documented procedure for identifying data gaps and scientific uncertainty and a technical, objective process to provide a reasonable scenario if site specific information is lacking; elimination of the concept of worst case analysis replaced with the concept of best professional judgment analysis; agencies' help in reviewing and directing initial drafts of impact assessments to help eliminate personal bias of preparers.
(3) The current regulation encourages an environmental bias which in some cases goes beyond the rule of reason, or other times simply stretches it.
(4) We are uncomfortable with a strict mathematical threshold standard; however, we believe it would be extremely useful to establish threshold guidelines of severe consequences, of probabiity, and of scientific credibiity. We urge creation of the advisory committee proposed earlier to deal with this specific topic.
(5) The concept of "worst case analysis" should be abandoned in favor of a concept such as "best professional judgment analysis", which has been used extensively by EPA in NPDES and RCRA programs. It should be defined as a "balanced, logical estimation of baseline conditions or impacts based upon extrapolation of all availabale information by a team of qualified technical experts."
If CEQ continues to use the worst case assessment concept, it should only be applicable when information is absolutely lacking and attempting to acquire that information is truly exorbitant; if there is a reasonable possibility (via a threshold mechanism) of the occurrences and impacts of the worst case event; if the information is essential to a reasoned decision, and if an appropriate environmental analysis cannot ocur within the conventional NEPA process. Further, it should be accompanied by a corresponding mitigation statement.

35. Regina Delahunt, Kerr McGee Corporation.
(1) An agency should only engage in forecasting when the potential effects are likely to cause significant harm to health or the environment. Forecasting implies a rational study and analysis of available pertinent data, whereas speculation implies theoretical rather than demonstrable knowledge. Whenever possible, the agency should avoid speculation and rely on forecasting.
(2) The analysis should be structured so that all interested parties can clearly recognize the amount of uncertainty present, perhaps by quantifying and "error factor" or by providing a range of possible results. Primary importance should be given to the most likely case.
(3) The regulation has required agencies to go beyond the rule of reason and there is a need to amend it to restore the rule of reason.
(4) A threshold standard should be established which encompasses severe consequences, probabiity and scientific credibility. It should also indicate that only reasonably forseeable events should be analyzed.

(5) The term worst case is not appropriate; a more appropriate term would be "reasonably foreseeable worst case" defined as a case for which "a reasonable possibility of occurrence has been proven based upon firm evidence in the actual circumstances of the proposed project."

36. T. S. Choo, Dow Chemical U.S.A.
(1) Under NEPA, an agency confronting scientific uncertainty or information gaps concerning the potential adverse and environmental effects of a proposed action must engage in reasonable forecasting or speculation of the reasonably forseeable effects of the proposed action.
(2) Agencies should follow scientifically accepted risk assessment procedures.
(3) The regulation, as interpreted by recent court decisions, has gone beyond the rule of reason by requiring the evaluation of all possible adverse environmental effects when there is any uncertainty about the potential adverse effects of a proposal.
(4) A threshold standard would be difficult to define, even with the factors listed in the ANPRM. The decision may be better left to the professional judgment of agencies' personnel, with the caveat that the threshold of probability is consistent with NEPA and the rule of reason.
(5) The term worst case is completely inapprpriate. The analysis should be called "environmental risk assessment" defined as the "procedure by which an agency evaluates the reasonably forseeable adverse environmental consequences of a proposed action on the basis of known or reasonably obtainable scientific data." Additionally, one agency should be permitted to rely on another agency's analysis.

Other comments: Dow supports PLF's petition and urges a favorable ruling thereon.

37. Michael Hertel, Southern California Edison Company.
(1) Almost any EIS will necessarily deal with forecasting and/or speculation, but one must be careful to differentiate between the two types of analyses. There is also a difference in "gaps in information" and "scientific uncertainty". "Scientific uncertainty" suggests uncertainty about apprpriate methodoloy for predicting and acquiring reliable facts, as well as uncertainty about the facts.
The analyses should focus on reasonable scenarios. It may be that the only way to determine which scenarios are reasonable are through the public participation process; for example, scoping.
(2) A viable procedure may lie in the matrix approach, combining thresholds of probability and degree of risk. An agency should be able to demonstrate causal relationships among the involved variables in establishing the "reasonable" nature of the action. The degrees of risk should be expressed in terms of a lower and upper confidence limit.
(3) We believe that the rule of reason dictates that a threshold triggering a worst case analysis must have some scientific standing or it should not be considered.
(4) We believe that the threshold concept is needed to determine when a worst case analysis should be required, combining in a matrix approach, thresholds of probability and degrees of risk. A common threshold should be avoided, particularly one using quantitative standards.
(5) The term "worst case" is the worst thing about the regulation; it can only arouse fear. A more neutral term such as "reasonable scenario analysis" would be more appropriate. The objective should be to provide the decisionmaker with a worst case and a best case analysis (representing the range of reasonable scenarios), and ultimately to determine or project the most likely case.

38. P.W.J. Wood, Exxon Company, U.S.A.
(1) In certain circumstances it may be appropriate to engage in a speculative analysis of impacts. We suggest that these circumstances could form the correct justification for a "worst case analysis" and that these tests include:
---what is the likelihood of an impact occuring?
---what is the significance of the impact?
---what data is available?
---is the data obtainable?
---can the data be acquired in a timely manner?
---the need for the project must be weighed against in the risk and severity of impacts if the decision is made to proceed in the absence of all relevant information. Need for the project should be defined

as the net sum of the social, economic, and/or environmental benefits and costs.

(2) Obvious remedies for avoiding misconceptions which have arisen from prior worst case analyses include:

---clearly and prominently identify the analysis as speculation plus a standard explanation of the purpose and form of the worst case analysis;

---the probability of occurrence should be quanitifed to the extent possible;

---all worst case analyses should be reported in a separate section of the EIS apart from analyses based on factual information supported by data.

We believe that specific impacts, rather than scenarios or a series of unlikely events, should be evaluated under these conditions. A two-step scoping process prior to the draft EIS could lay the groundwork for such analyses. Editorial opinion should be eliminated.

(3) NEPA, like all statutes, must be construed in the light of reason. We see no justification that would compel a worst case analysis beyond the rule of reason associated with other NEPA issues. The problem with the existing regulation is that it leaves room for an agency or plaintiff to argue that it goes beyond the rule of reason. Thus, we feel it is necessary to more explicity define the rule of reason in the context of the regulation

The rule of reason as it relates to worst case analysis actually involves two applications of the rule. The first asks whether the worst case event if actually possible: could the event occur? If it could, and if there is a meaningful possibility of occurrence based upon past experience or sound scientific principles, the worst case rule is triggered. The rule of reason should prevail in letting an agency decide whether a certain event meets these standards; however, CEQ should attempt to place some boundaries or guidelines in the regulation on what type of an adverse event qualifies for the analysis.

The second application of the rule of reason relates to the scope of the worst case analysis once the rule is triggered: how far should the analysis go in identifying the adverse impacts and consequences of the worst case? Reasonable limits must be applied to prevent the analysis from becoming an open-ended inquiry into the world of the unknown. The scope of the analysis should be limited to likely impacts and consequences. The agency should only be required to actually analyze the most probable outcome of the worst case. The current regulation does not address this point, and therefore leaves the question open.

(4) In practice, developing a universally accepted threshold standard is exceedingly difficult. In our opinion, a worst case analysis should not and is not required in every situation where there is a gap in information or scientific uncertainty; it is not required when the potential impacts are not significant or when the probability that the event will occur is small (de minimus). Since we believe it may be impossible or very difficult to establish unvirsal threshold standards, we believe that the decision on whether to conduct a worst case analysis must be left to the appropriate agency.

(5) The term worst case is a misnomer; the type of analysis called for in the regulation is really an analysis of risk, defined as the possibility of suffering harm or loss. The goal should be: a) to determine what events could cause harm or loss; b) what would be the extent of the harm or loss; and c) the probability of the event occurring. It must also incorporate the certainty of the relevant data and the extent of relevant experience. If this analysis is to be presented as a separate section of the EIS, we suggest that the title be, "Analysis of Uncertain Events of Effects."

Attachment: "Examples of Inappropriate 'Worst-Case'Scenario Analysis

39. David Jessup, Oregon Forest Industries Council.

(1) A federal agency should not be required to forecast or speculate on an unknown. Such analyses could only be very subjective.

(2) Reasonable can only be based upon a preponderance of relevant scientific evidence which can show the probability of one or more results of a proposed action. If there is insufficient evidence, the agency can either try to obtain more information through research or other

documentation resulting from observation. Another factor to be considered is whether the gap or uncertainty is of such a natuure that it would alter a decision.
(3) Yes, the Ninth Circuit has in essence required the agencies to speculate about what might happen even when there is no scientific evidence that an event wil occur.
(4) A threshold should be established based on some form of credibly established knowledge that certain different effects would be found if the missing information is found.
(5) "Worst case" is too speculative a term. We should rather look at what is most likely to occur under a spectrum of scientifically based probabilities because of events known to have occurred before under similiar conditions.

40. John Kearney, Edison Electric Institute.
(1) EEI believes that it is beyond the purposes and requirements of NEPA to engage in speculation when confronted with uncertainty or gaps in information. There should be an identification and a discussion of data gaps and uncertainties, and differences in scientific opinion should be pointed out. The assessment of potential environmental impacts should be based on existing or reasonably obtainable data and should discuss what is reasonably forseeable.
(2) It is very difficult to structure an analysis to present reasonable forecasting in the face of scientific uncertainty or data gaps. The most effective approach is to identify the uncertainty or gaps and briefly present a common sense portrayal of how the discovery of new infomation could alter the conclucsions reached in the EIS concerning reasonably forseeable impacts.
(3) The SOCATS decision suggests that this analysis requires agencies to go beyond the rule of reason; it is potentially unreasonable to require detailed forecasting in the face of data gaps or uncertain information. EEI believes this confusion could be eliminated by combining the analysis now required under 1502.22 with the consideration of reasonably forseeable environmental impacts under 1508.8.
(4) The rule of reason requires a threshold to be based on scientific credibility.
(5) The term "worst case" is inappropriate tne may overshadow the more probable environmental effects which are addressed in an EIS.

41. David Dietz, Pesticide Public Policy Foundation.
Amendment of the regulation is strongly needed. CEQ has both the right and obligation to correct the abuses which exist because of the Ninth Circuit's interpretation of the regulation. Further, the need for a rule of reason to guide the government's work on behalf of the citizenry is beyond question. We urge CEQ to move forward to amend the regulation.

42. Frederick Provorny, Monsanto.
(1) An agency should consider all avaiable information, incuding the existence of scientific uncertainty, in determining which effects will occur or are reasonably foreseeable because of the proposed action. It need not speculate, but when there are sufficient data to indicate that an effect is reasonably foreseeable but that its ramifications are unknown the worst case analysis may be used to complete an EIS.
(2) The situation in which an agency must resort to speculation, i.e., the worst case assumption, should be limited to those situations in which the agency is examining a reasonably foreseeable effect and valid data on the full range of implications of that effect cannot otherwise be reasonably obtained.
(3) The regulation should be amended to indicate that agencies should not go beyond the rule of reason.
(4) It is highly improbable that a reasonable threshold that can be established to encompass all of the potential situations which can arise under the CEQ regulations. Our suggested amendments provide some help in bringing reasonable foreseeability and significance into this analysis.
(5) The term "worst case" is inappropraite. Instead, the concept should be described as an "assessment of the rasults of reasonably foreseeable effects."

Attachments: Marked-up version of following regulations as suggested amendment: 1502.22, 1508.8, 1508.27; Brief of Amicus Curiae Monsanto Company in support of Petition for Writ of Certiorari in Southern

Oregon Citizens Against Toxic Sprays, Inc. v. Clark; Brief of Amicus Curiae Monsanto Company in Merrell v. Block, United States Court of Appeals for the Ninth Circuit.

43. John Shepherd of Holland & Hart, on behalf of the Anschutz Corporation. The current regulation is causing agencies to perform worst case analyses when such "worst cases" are extremely remote; much time and money is being wasted in such work. If this trend continues, companies will stop agreeing to pay for environmental analysis work, and the agencies will have to shoulder that burden again.

The two subsections in part (b) of the regulation do not make any logical sense, and this has been borne out by recent case law.

The failure to tie worst case analysis to events that have some reasonable probability of occurring means that such analyses are rarely useful to anyone.

In Mr. Yost's article, he suggests that the regulation was designed for the potentially "catastrophic event", e.g., a melt-down at a nuclear power plant. If this was intent, the regulation should be revised to reflect this.(Yost, "Don't Gut Worst Case Analysis", 13 Envtl. L. Rep. 10, 394 (1983).

It is extremely difficult to define what the "worst case" is in any given situation.

Courts are applying worst case requirements to environmental assessments, which is not reasonable because by definition, EA's are not prepared when the environmental impacts are significant.

Recommendations:

a. The worst case requirement should contain a threshold of probability, at least for events that are not catastrophic;

b. The interpretation problems mentioned above should be resolved;

c. CEQ should make it clear that the requirement does not apply to an EA.

44. J. Allen Overton, Jr., American Mining Congress.

(1) A federal agency should only engage in forecasting or speculation when confronted with scientific uncertainty or gaps in information concerning the environmental effects of a proposed action when the potential effects are likely to cause significant harm to the environment. The extent of forecasting and speculation should be dictated by the severity of potential impacts. Only those impacts which are reasonably foreseeable should be evaluated in depth. The extent of forecasting should also be determined by the availability of a scientifically credible methodology and reliable data.

(2) The analysis should be structured so that all parties can clearly recognize and understand the level of uncertainty inherent in the analysis. This can be partly accomplished by specifying an "error term" surrounding the results. A central position should be given to the most likely case.

(3) The type of analysis called for in the regulation and the guidance in CEQ's "Forty Most Asked Questions Concerning CEQ's NEPA Regulations" have indeed caused agencies to go beyond the rule of reason. There is a need to amend the regulation to restore the application of the rule of reason.

(4) We suggest five sequential tests to establish a threshold for a worst-case scenario:

a) relation to the proposed action;
b) minimum data base;
c) severe environmental consequences;
d) probability of occurrence;
e) scientific credibility.

(5) The term "worst case" is not appropriate. A better term would be "adverse-case analysis" where the adverse case to be analyzed will be a reasonably forseeable worst case for which a reasonable possibility of occurrence has been shown upon a firm evidentiary basis given the actual circumstances of the contemplated project and which meets the threshold tests listed in question 4.

45. D.L. Stevens, Freeport Exploration Company. The regulation should be amended to more accurately reflect the rule of reason.

46. Marcus McCraven, United Illuminating. Supports comments submitted by Edison Electric Institute.

In addition, wishes to emphasize that the worst case analysis is not necessary and that an environmental analysis needs to focus only on those impacts which are reasonably foreseeable, based upon the rule of reason.

47. Scott Horngreen, Western Timber Association.
CEQ must change the direction that worst case analysis headed. "The preservationists want to expand the worst case analysis requirements as broadly as possible. Worst case analysis is becoming a wildly speculative venture into Chicken Little forestry. CEQ must establish a threshold of 'reasonable foreseeability' before a worst case analysis is required."

48. David Zoll, Chemicals Manufacturers Association.
(1) When confronted with scientific uncertainty, agencies must make estimates of data based on the result of informed analysis by knowledgeable exprts. Where valid evidence does not exist to support an assumption or data estimate, it should not be included an EIS. We recognize that there are occasions in which an agency must act on less than complete data; in such circumstances an agency should engage in reasonable speculation.
(2) An analysis should be structured to display the range of potential environmental impacts and the probability of each impact occuring. The EIS should assess a spectrum of events, ranging from impacts of high probability but low impacts to impacts of low probability but higher impacts. The assumptions should he explicitly stated.
(3) Some have interpreted the regulation to require analysis of impacts which are remote, speculative or irrelevant; the regulation should be modified to make clear that analysis of such impacts is not required.
(4) A threshold standard such as mentioned in the ANPRM would be difficult to define. The decision may be better left to the professional judgment of the EIS preparers.
(5) The term "worst case" can be misleading. We urge CEQ to eliminate the term. Rather, the regulation should require that impacts must be analyzed if: a) the impacts have a reasonable probability of occurrence; b) the probability of the impacts' occurrence is relevant to the agency's decision, and c) there exists a sufficient data base for an analysis which is not unreasonably speculative.

49. Mark Schneider, SOHIO, Standard Oil Company. Endorse comments from API, Alaska Oil and Gas Asssociation, and the Rocky Mountain Oil & Gas Association.
(1) Analysis should be bounded by the rule of reason. A well reasoned decision and associated project modifications would be enhanced by an EIS that focused greater attention on likely events and would be less alarming to the local communities. Speculation and forecasting should not go beyond reasonable and prudent limits.
(2) Risk analysis assoiation with the specific project and interpretation of data surrounding that project is one way to structure a more reasonable forecasting method for scientific uncertainty and data gaps regading the effects of propsoed action. In our opinion, any "worst case" analysis is unnecessary.
(3) The regulation appears to require a worst case analysis regardless of he rule of reason.
(4) We believe that consideration of all; reasonably forseeable events and consequences of a major federal action should be adequately considered and addressed by the decisionmaker. Thresholds of severe consequences, probabiity, and scientified credibility modified by a reasonability standard would be useful in establishing criteria by which potential consequences of a project could be analyzed.
(5) "Worst case" is inappropriate. Perhaps the analysis could be defined as "reasonably forseeable events". Then by applying the tests of probability, severity, and scientific credibility, the regulations could point to reasonble time frames and provide an economic feasibiity test to require only prudent costs for obtaining information necessary to make a balanced decision on a major federal action.

50. Russel Weisensel, Wisconsin Agri-Business Council, Inc.
We support amending the regulation to eliminate the worst case analysis. THe rules should be amended to allow the rule of reason to prevail so that agency management practices can be based on realistic assessment of risks and benefits.

51. William Hopkins, Alaska Oil and Gas Association. There is risk in everything that mankind attempts to do. Agency should analyze research data directly or partially applicable to the issue under review. If data are not available on a specific locale or specific species, extrapolation of data on similiar locales or species could be used. Assumptions in the analysis should have a reasonable likelihood of occurring.

Industry has been concerned with agencies misusing or selectively using data on oil spill occurrences, their causes and impacts. Agencies should engage in predictive analysis only when data gaps are significant or relate to a substantial adverse effect that is reasonably likely to occur. Risk assessments or probability analyses can be done to assess the need for specific impact assessment.

The data base and assumptions used in the analysis should reasonably relate to the conditions and circumstances which govern the human activity being considered. Boundaries for worst case analyses can be established by statistical means assigning values to the probabilities of certain negative events occuring and the effects that could result. Thresholds below which a worst case analysis must be performed can be established in relationship to probability.

If a worst case analyis is called for it should be preceded by the probability of it occurring as well as the probability of the reasonably forseeable consequences occurring.

52. Patricia O'Toole. Union Oil Company of California.
NEPA does not require that information gaps be filed or areas of scientific uncertainty be resolved prior to approval of an EIS; rather, the EIS must address all potential environmental effects. To address information gaps or uncertainties, management agencies may issue "conditional" permits or approvals and allow the accumulation of additional information concurrent with implementation of the proposed action.

We believe that when an agency must engage in forecasting and speculation to determine probable scenarios, it is imperative that the agencies exercise the rule of reason. That is, probable scenarios must be based on a reasonable probability, rather than the possibiity of events occurring. We suggest that a quantitative level of probability be defined in the regulation to guide agencies in the creation of realistic worst case scenarios.

53. Steve Goss, U.S. Borax. We request that the regulation be amended to better effect a rule of reason.

54. Ken Bennett, Phelps Dodge Corporation. We request that the regulation be amended to better effect a rule of reason.

55. Roger Nelson, Utah International, Inc. The term "worst case" and the concepts embodied therein are intellectual absurdities. They are impossible to define or achieve. The more useful question which should be asked is, "what are the environmental impacts of the reasonably forseeable adverse case?"

56. John Rucmick, Exploration Ventures Company, Inc. We request that the regulation be amended to better reflect the rule of reason.

57. C. C. Hawley, Hawley Resource Group, Inc. We request that the regulation be amended to better effect a rule of reason.

58. Jack Swenson, Rocky Mountain Oil & Gas Association, Inc.
(1) Speculation may occur as to possible impacts of a proposal when there are information gaps or scientific uncertainties, but it should not become worst case analysis unless: a) the unknown information relating to adverse impacts is essential to a reasoned choice among alternatives; b) the overall costs of obtaining the information must be exorbitant, or there is no known way to obtain the information; c) possible adverse impacts are severe enough to warrant speculation; d) it is probable that the proposed severe consequences could occur; and e) the agency believes it will proceed with the proposed action in the face of uncertainty.
(2) We suggest the following as guidelines for forecasting;

a) restrict speculation to the action proposed rather than all conceivable consequences of that action;
b) limit speculation to events that have some probability;
c) require speculation only if the proposed action will probably be approved;
d) limit the speculation to information that is material and relevant to the proposed action and its reasonably probable consequences.

(3) The regulation should not not go beyond the rule of reason, but as written, it does. The section now appears to require such analysis without first asking if it is reasonably probable that a worst case event might occur.

(4) Yes, thresholds should be established as per the five criteria listed in the response to question 1, and, additionally, a standard of scientific credibility should govern the preparation of the analysis.

(5) The term "worst case" is appropriate and must be distinguished from the term "environmental impact". Worst case analysis occurs only when events are probable, outcomes are likely to be catastrophic, there is no way to obtain relevant information or necessary data and costs of obtaining such information or data are exorbitant. Further, it is (or should be) governed by the rule of reason.

59. E.P. Rahe, Westinghouse Electric Corporation, Water Reactor Divisions, Nuclear Technology Division.

(1) We do not believe there are any circumstances under which a federal agency must or should engage in speculation when confronted with scientific uncertainty or gaps in information. Because, by necessity, there is some uncertainty involved in almost every EIS, an agency must engage in some form of analysis of future impacts based upon available data. However, the analysis need only consider environmental effects which are reasonably foreseeable.

The regulation fails to incorporate reasonable limits for worst case analysis and the guidance in the "Forty Questions" stating that all known possible environmental effects had to be addressed compounded an already confused situation. We believe that the regulation should be amended to replace the word "possible" in Section 1502.22(b)(2) with the phrase "reasonably foreseeable" (adverse impacts).

(2) There would be relatively few instances where a proposed action resulted in reasonably foreseeable environmental impacts under circumstances where there was significant scientific uncertainty or information gaps about the magnitude of those impacts. In such instances, the rule of reason standard should be applied.

(3) We believe that the regulation goes beyond the requirements of, and contravenes, NEPA by attempting to require conservative, rather than realistic, environmental impact assessments.

(4) The threshold should be probability; that is, is the environmental effect (about which some scientific uncertainty exists) a reasonably forseable effect of the proposed federal action?

(5) The term "worst case" is not appropriate. The most appropriate term for this type of analysis would be a "realistic" analysis which would be an analysis using the current state of scientific knowledge which would assess the magnitude of the environmental consequnce that the scientific community thought to be probable or reasonable.

60. C.E. Sandler, American Petroleum Institute. We believe that the use of the worst case analysis is only valuable when the risks associated with reducing uncertainty are clearly unreasonable, when risk assessment methodology based upon the best available science is used, when the worst case is a reasonable and plausible outcome, and when the probability of the distribution of plausible outcomes is explicitly part of the decisionmaking process. The regulation should be clarified to adopt this line of reasoning. Under the current regulation, worst case analyses can be, and have been, misapplied resulting in serious delays in petroleum projects, endless litigation, and burdensome lease stipulations designed to mitigate the speculative impacts from highly unlikely events. API believes that the decisionmaker should be concerned with what might probably happen, not what might conceivably happen. (Lengthy discussion of risk assessment practices). API endorses comments from the Rocky Mountain Oil and Gas Association.

Enclosures: API's comments on EPA's Determination of Significant Risk and Advance Notice of Proposed Rulemaking for Formaldehyde, 8/3/84. API's comments on EPA's Proposed Guidelines for Exposure Assesment, 1/22/85.

API's comments on EPA's Proposed Guidelines for Carcinogen Risk Assesment, 1/22/85.

61. Roberta Anderson, Amoco Production Company, Denver Region.
Amoco Production Company strongly urges that the CEQ Guidelines be completely revised in accordance with the recommendations contained in the Report of the Presidential Task Force on Regulatory Relief. In respect to Section 1502.22, we commend to your attention the Task Force's guideline which states in part that, "To be useful in determining overall benefits and costs, risk assessments must be scientifically objective and include all relevant information. In particular, risk assessments must be unbiased best estimates, not hypothetical 'worst cases' or 'best cases'. Extreme 'best' or 'worst' safety or health results should be weighted (along with intermediate results) by the probability of their occurrence to estimate the expected result implied by the available evidence. . . ."

62. Robert Fugitt, DuPont.
(1) We agree that it is appropriate to speculate regarding the worst consequences of any given action; however, such speculation must be restrained to consequences that may reasonably be anticipated. The speculation cannot be endless.
We suggest that any worst case analysis involving the use of an EPA registered pesticide may be inappropriate. Review beyond EPA review is redundant. We do not believe that Congress ever intended NEPA to require other federal agencies to duplciate the EPA review.

63. Paul Sheidig, Southwest Forest Industries.
(1) Federal agencies must engage in reasonable forecasting or speculation when confronted with scientific uncertainty or information gaps concerning the environmental effects of a proposed action. Prior to recent court interpretations of the worst case analysis regulation, the agencies analysis was bounded by a reasonableness standard. That should still be the standard; that is, the decisionmaker should gather the information sufficient to make a reasoned choice of action. NEPA does not and should not require that federal decisionmakers waste time and energy considering highly speculative consequences.
(2) CEQ should not mandate any specific structure for analysis, but only that the decisionmker use scientifically sound analytical procedures. Universal requirements would soon become arbitrary or antiquated.
(3) Recent court decisions interpreting the regulation have required a degree of analysis beyond the rule of reason. Rather than requiring that an agency consider "probable" or "reasonably forseeable" adverse environmental impacts, the courts have held that agencies must evaluate all possible impacts and the probability of their occurrence. To consider all possible impacts is extremely difficult, because it is almost infinite.
(4) The trigger for additional analysis should be: if the information relevant to adverse impacts is essential to a reasoned choice among alternatives and that information is not available to the decisionmaker. This is actually the current trigger. The problem is in the recent court decisions where there has been a misinterpretation of when some missing information is "essential" to make a reasoned decision. In recent decisions, the courts have considered virtually any difference of opinion among experts as sufficient to trigger a worst case analysis. CEQ must explore how to craft such a trigger which will not be subject to such damaging misinterpretations.
(5) The additional analysis should not be called "worst case".

64. Peter Briggs, Atlantic Richfield Company.
(1) Forecasting or speculation in the face of scientific uncertainty or data gaps should be determined by objective thresholds within the context of the proposed action. Worst case analyses should differ, depending upon whether the action is a federal proposal or a private action requiring a federal permit. For a private action, the analysis should deal with the proposed action as a given and the mitigation measures as the only possible alternatives. In theory, at least, a government action is more ameneable to change. In either case, there should be a finite limit to the worst case analysis before reaching pure fantasy.

(2) The analysis should meet the tests outlined in response to question (4). Also, it should be made clear that the worst case analysis is highly biased for a particular purpose, and that it should not be used for local planning.
(3) We defer to RMOGA's comments.
(4) We suggest six appropriate thresholds or tests, that are sequential. which would precede the determination of whether an agency had to engage in a worst case analysis:
----relation to the proposed action;
----minimum data base;
----severe environmental consequences;
----probability of occurrence;
----scientific credibility
----impacts increased by the proposed action.
We do not believe that CEQ should try to quantify these thresholds.
(5) We believe that worst case may be the appropriate term, as long as there is a clear understanding and correct application of established thresholds and the rule of reason applies to the analysis.

65. Robert Kirshner, National Forest Products Association.
(1) When scientific uncertainty or information gaps are of a magnitude to keep the decisionmaker from being able to make a reasoned decision among the alternatives after taking a "hard look", reasonable forecasting or speculation is necessary. That process is governed by the rule of reason; the decisionmaker gathers the information needed to make a reasoned choice of action. However, agencies should not have to consider every possible consequence.
(2) CEQ should not mandate any specific structure for analysis, but only require that the decisionmaker use scientifically sound analytical procedures.
(3) Recent court decisions interpreting the worst case analysis regulation have required analysis far in excess of the rule of reason. The courts are requiring a breadth of analysis which is time consuming, costly, unnecessary, almost impossible to perform, and easily attacked. Even after exhaustive study, there may always remains an additional "possibility". Uncertainty should not trigger an additional process, just an additional step in the process.
(4) A threshold standard based on the rule of reason should be established to trigger any initial analysis. The trigger should be: if the information relevant to adverse impacts is essential to a reasoned choice among alternatives and that information is not available to the decisionmaker. This trigger is identical to the current language in the regulation; the problem is recent court decisions which make the existence of virtually any difference of opinion among experts sufficient to trigger the worst case analysis.
(5) The analysis should not be called "worst case". Consideration of a hypothetical worst case will not aid the decisionmaker; it is more important to consider the probability of the reasonably forseeable consequences.

66. Joel Patterson, Middle South Servics, Inc.
(1) In a sense, all EIS(s) by their very nature deal with unknowns and uncertainties, since they are prepared prior to the proposal's implementation. However, forecasting and speculation should be used only when the agency has sufficient information available to make an informed judgment on the potential effects of an action. The whole concept of "worst case" is clearly subjective; an EIS is the place for objective criteria and not for such "prognostication".
(2) There are too many variables involved in the diverse number of projects subject to NEPA to require any particular type of structured analysis.
(3) The regulation clearly asks the agencies to go beyond the rule of reason. Under the current rule, the analysis will be based on pure speculation.
(4) A threshold is a commendable idea. Of the three thresholds mentioned in the ANPRM, the only one we would object to would be a threshold of severe consequences. The threshold should be based on the rule of reason, and should limit worst case analyses to reasonably forseeable impacts about which there is adequate information available to make an informed judgment concerning potential effects.
(5) Our major recommendation is to eliminate Section 1502.22 completely. However, if this is not done, we have no problem with the use of the term "worst case" if defined so that the analysis is limited to

reasonably foreseeable impacts that have sufficient information available for the agency to make an informed judgment concerning potential impacts.

Other comments: We believe the entire section should be deleted. It is responsible for numerous court cases and may hinder decision-making by turning a scientifically based document into a speculative document. It is not needed to accomplish the goals of NEPA.

If this advice is not followed, we suggest that CEQ: 1)state in the regulation that only those impacts that are identified as significant in the scoping process will be addressed in the EIS; 2)provide the agencies with a threshold of probability and/or scientific uncertainty based on the ule of reason; and 3)indicate that not every EIS requires a worst case analysis and indicate when it is necessary.

67. R. R. Kienle, Shell Oil Company.
(1) It is essential to distinguish between the types of "scientific uncertainty or gaps in information" which confront a federal decision-maker. In some cases, there is substantial knowledge as to the likelihood of an environmental accident and its general impacts if it occurs. However, given the extreme improbability of some occurrences, such as an oil spill during Outer Continental Shelf projects, and the vastness and duration of such projects, there is an inevitable uncertainty as to whether an oil spil will, in fact, occur during the life of the project, and if it does, where and when it will occur and how much oil will be spilled. In this type of situation, a worst case analysis is mandatory only if uncertainty exists as to either probabilities or consequences.

A completely different type of uncertainty - typified by spraying of herbicides - is where there is scientific uncertainty as to the impacts of an occurrence, which is itself certain to take place. A worst case analysis may be necessary for this type of uncertainty.

Further, the distinction in the regulation between information which is only available at exorbitant cost and information which cannot be obtained is unwise. See attached suggested redraft of regulation.
(2) We believe that the structuring of the analysis would be more useful and understandable if the regulation is changed per our suggested amendment.
(3) We do not believe that an EIS should discuss remote and highly speculative consequences; there is a point at which the probability of an occurrence may be so low as to render it almost totally unworthy of consideration. As it stands now, "the regulation could be subject to misinterpretation by overzealous defenders of the environment and members of the judiciary."
(4) We would propose the following tests for the "worst case reasonably forseeable":
---the impacts are a forseeable consequence of the proposed activity due to the lack of knowledge at hand;
---a reasonable possibility of the event leading to the set of adverse impacts has been proved upon a firm evidentiary basis in the actual circumstances of the contemplated project;
---the likelihood of the event leading to the set of adverse impacts is shown to be significantly increased by the performance of the project; and
---there is a basis of evidence recognized in the scientific community which makes the adverse consequences something more than mere speculation by the lay observer.
(5) Shell supports the adoption of the "worst case reasonably forseeable." This would be a defined as a particular set of unknown facts which can be defined as the most castrophic set of circumstances which could arise out of the proposed activity and which meets the criteria discussed in our answer to (4) and is forseeable due to the lack of information at hand. The regulation should make clear that such analyses are required if all the other conditions of the regulation are satisfied and the proposed activity warrants preparation of an EIS.

Attachment: Proposed Amendment to Section 1502.22(b).

68. California Mining Association.
"Worst case analysis procedures, fueled by a lack of information and failure to understand NEPA intent, are contributing to conjectural forecasting and decisionmaking. The sound guidance and logical perspectives needed for reasoned decisions are severely inhibited and overly influenced by worst case analyses. More unfortunately, perhaps,

are the false and alarming impressions created by unlikely and potentially impossible situations upon which a new project may be judged by its neighboring, but ill informed public."

CEQ should establish the use of a rule of reason in worst case analyses. Several criteria may be considered in establishing such a rule, such as a threshold of "reasonable probability". The expected impact on the affected population, the expense involved in gathering the information and the scientific capability needed to appraise the situation should also be factors. Balancing such factors should lead to an appropriate decision as to which impacts, if any, should be considered in a worst case analysis. Such assessments, however, should only be required in unusual circumstances.

Changes and clarification are overdue in relation to the worst case issue.

PUBLIC INTEREST ORGANIZATIONS

1. Ilona Gray, Executive Director, The Alliance for Environmental Concerns. "We cannot accept . . . as a philosophy that a risk free society is desirable. A worst case situation analysis can be easily manipulated into a long slow and costly 'no' to any real advancement." Urges consideration of the petition submitted by the Pacific Legal Foundation.

2. Ronald Michieli, Director, Public Lands Council, National Cattlemen's Association, National Wool Growers Assocation. (1) An EIS should consider only events that may have a possifility of occurring, using the rule of reason.
(2) The analysis should focus on the nature and extent of the information gaps and uncertainty without drawing all the conclusions that the human imagination could devise.
(3) It is eminently clear that the regulation goes beyond the rule of reason and that is the cause of the recent court decisions. The regulation prompts "wild or unreasonable speculation about improbable events that have the most remote possibility of occurrence and about remote consequences that are fantasy unbridled."
(4) A threshold of reasonable probability should be established, to be proven on some evidentiary basis.
(5) The term "worst case" is inappropriate and may be at the root of the current difficulties. No substitute term is needed; the regulations should simply indicate that some analysis of possible adverse impacts should be undertaken when there is evidence of reasonable possibility of an event occurring from a propsective project or agency decision.

3. Daniel J. Popeo, George C. Smith, Washington Legal Foundation.
(1) An agency should never be required to engage in actual "speculation" with respect to analysis of environmental impacts. NEPA is designed to focus attention on significant and probable, or at least reasonably likely environmental impacts. The most that should be required in such cases is the identification of the reasonably forseeable adverse impact as to which there is a gap or uncertainty in scientific information.

Disciplined and scientifically sustainable forecasting (as distinguished from speculation) might be required of an agency when each of the following factors applied to a potential adverse imnpact event as to which there is scientific uncertainity of a gap in availlable information: a) the potential adverse impact upon the human environment, in terms of health or safety, is highly significant in terms of severity and scope; b) the likelihood of occurrence is more than "extremely low" and there is at least a demonstrable and reasonable possibility that the impact event will occur; c) the likelihood of the adverse impact is significantly and measurably increased by the federal action at issue. In these circumstances, the agency could be required to assess the available data and scholarship, identify and describe it in the EIS, and characterize or quantify its likelihood of occurence.
(2) This question is more properly addressed by scientific or technical commentators; however, the more remote and speculative a potential impact, the less likely that an analysis will be usable and reliable.
(3) Yes, the current regulation goes beyond the rule of reason, which should apply to this type of analysis.

(4) Yes, a threshold is needed as suggested in our previous answers.
(5) "Worst case" is an inappropriate term. The more appropriate term would be "Impacts of Low Likelihood but Severe Consequences."

4. Michael Axline, Pacific Northwest Resources Clinic. "I am appalled at the CEQ's serious consideration of an amendment to 40 C.F.R. 1502.22. Rather than explaining to federal agencies that a worst case analysis requires nothing more than an honest disclosure of responsible opposing opinions and potential impacts, the CEQ is apparently participating in unfounded hysteria caused by misreadings of the opinions of the Ninth Circuit . . . The courts did not order the agencies to engage in wild speculatio or consider every possible consequences. . . . If it is truly your goal to more effectively implement NEPA, I suggest that a concise, accurate memorandum to federal agencies explaining the context and meaning of the Ninth Circuit opinions would achieve that goal. Amending 40 C.F.R. 15022.22, however, is directly contrary to such a goal. (3) The regulation does not require agencies to go beyond the rule of reason.

5. Nicholas C. Yost, Center for Law in the Public Interest. Submitted article, "Don't Gut Worst Case Analysis", 13 ELR 10394 (1983) in the record.

6. David Dietz, Oregonians for Food and Shelter.
We cannot live with the Ninth Circuit's interpretation of 40 C.F.R. 15022.22. "The judicial interpretations threaten our environment, have damaged our economies and have laid the base for endless, destructive litigation." "The judicial logic applied to the federal use of herbicides has equal applicabiity to other pesticides and other chemicals for other federal agency uses of these management tools."
(1) "'Forecasting' is the act of planning in advance, or the estimating or calculating in advance, as in predicting or prophesying. 'Speculation' is the act of mneditating, pondering or, especially, conjecting.'" Neither forecasting nor speculation should ever be required under NEPA.
(2) When confronted w/scientific uncertainty or information gaps, an agency should go through a 3 step process:
   a) Is the event probable?
   b) Is the gap or uncertainty relevant?
   c) Is the available data base sufficient to permit a reasoned evaluation of the expected effect?
"By structing an analysis in this manner, an agency does put before itself and the public reasonable, relevant information concerning information gaps and/or scientific uncertainities. . . Endless speculation or crystal ball prophesying is ended because reliable data bases must exist, or be readily obtainable, before engaging in an actual estimation of impacts. And, the decision-makers meet NEPA's mandate to review expected environmental consequences before proceeding with a proposed action: They act with open eyes and so, too, does the public.
(3) Under current Ninth Circuit Court decisions, the regulation does go beyond the rule of reasons. Suggests the Fifth Circuit's decision in Sierra Club v. Sigler does embody the rule of reason.
(4) A procedural threshold should be established, but not on the basis of some statistical "trigger". The threshold to trigger a worst case analysis should include:
   a. That missing information or data gaps regarding effects flow from an identified, probable event;
   b. That the missing information or data gaps have relevance for expecting a significant effect from a known event; and,
   c. That a supportable data base exists, or can be obtained at less than exorbitant costs, to accurately and reasonably postulate expected effects.
(5) The term "worst case" is not appropriate. As now understood, it speculates that some event will result in some possible effect, with or without data to support the analysis.
   Instead, the process should become an estimation of scientifically probable effects from known event.

Additional comments: It is imperative to amend the regulation. The Ninth Circuit opinions are "unnecessary, burdensome in the extreme and compliance is arguably an impossibility, or at the least, an invitation for endless litigation."

7. Jerry Rodhe, California Coalition for Alternatives to Pesticides.
CCAP firmly believes that there is no need to change the regulation.

The regulation is clear and comprehensive and is necessary to insure protection of the environment; the recent case law has amplified and explianed it. The attempts to alter the requirement stem from "the desire of private industry and selected agencies to pursue a plicy of 'spraying as usual', despite evidence that this policy may lead to harmful, and even tragic, consequences. The recent lethal toxic disaster is Bhopal, India, is compelling proof of the existence of 'worst case' events, and should e sufficient reason for to maintain the regulation in full force.

The Council would better spend its time lookig for ways to improve environmental quality, rather than attempting to dismantle regulations designed to protect it.

8. James Pacholke, Panhandle Environmental League (Idaho). "We are objecting most strongly to the attempt to eliminate the legal requirements to establish the 'worst case analysis'. Since most scientific analysis and many experts in all fields have varying ideas and data as to what is safe and what is not, it is the federal government's obligation to protect the citizens by assuming the worst case analysis when data is missing, rather than assuming that nothing wil happen.. . . We object to the attempt by the executive branch . . . to circumvent the judicial branch by this proposition."

9. Marion Miller, South Fork Trinity Watershed Association. It is inappropriate for our group to respond to the speciic questions, as it is our position that the present regulation is adequate and necessary and should not be alterecd. We are perplexed as to why CEQ is launching an initiative against this regulation which is designed to offer the public reasonable protection against assaults on the environment and affected populace. Object to publication of notice on New Year's Eve.

10. Sally Yost, Friends of Plumas Wilderness. We urge CEQ to leave the regulation intact. "We, private citizens, should be protected to the maximum extent possible when it comes to the use of chemicals and any questionable forest practices on the environment. When there are information gaps about the environmental or safety effects of proposed actions, a worst case analysis should be done in order to protect us and future generations."

11. Roger, Bee Mountain Community. CEQ should strengthen the worst case regulation. It goes byond the rule of reason not to include a worst case analysis in considering the possible use of any hazardous substance.

12. Ken Oleari, Salmon River Concerned Citizens. The regulation is adequately written and is vitally important in protecting the human environment.

13. Edwin Stockly, Idaho Natural Resources Legal Foundation, Inc.

(1) Once an agency identifies the existence of scientific uncertainty or gaps in information, then the agency should discuss not ony what the agency thinks will happen but what might happen if the agency's assumptions are incorrect. The best action is taken when there is a consideration of all that might go wrong and an intelligent weighing of the probabilities.

(2) "I think the analysis should set forth the nature of the scientific uncertainty or the gaps in the information. It should then set forth the assumptions that are being made and the reason for those assumptions. The analysis should contain a listing of what could happen in the event the assumptions should prove incorrect. If it is possible, the analysis should contain a listing of alternate assumptions that might prove to be more accurate and a statement of what could follow if that were the case. The purpose of all of this is to provide as much information to the decision maker and to the public and also, as the dcision is to adopt the proposal, to provide enough indication to those who are in charge of the operation what might go wrong and when and how to tell that it is going wrong."

(3) I do not think the regulation goes beyond the rule of reason. The rule requires the preparation of the worst case analysis when significant information is lacking. If that kind of information is lacking, then it is reasonale to consider what could go wrong.

(4) The problem I have with thresholds is the possibility of structuring reports to evade the threshold. Admittedly, requiring worst case analysis

under the current rule is not the clearest standard in the world, but the cases are clarifying it and after a reasonable amount of time, everyone should understand what is meant.
(5) No opinion.

14. L. A. Scott, Inland Regional Council, (Northwest Coalition Alternatives to Pesticides).
(1) "We believe a good worst case analysis should cover the entire spectrum from the least harmful to the worst possible case and also include what government experts analyze to be the most likely effect."
(2) The structure of a reasonable forecast must weigh all available information, taking into account the least harmful and most likely scenarios as well as the worst case.
(3) Yes, it is extremely reasonable to weigh the worst case's consequences if the fundamental facts underlying the decision to be made are unknown.
(4) "The standard of reasonableness must also apply here [to a threshold]. If there are scientific uncertainty or data gaps, the implementing agency must show that the consequences and probability wil be minimal and inconsequential. This would be the threshold we would endorse as the scientific credibility of pesticide research is often questionable and uncertain."
(5) The term "worst case" is appropriate. We would define it as any harmful or deleterious effect that should, could or might occur if the program is implemented.

Other comments: NEPA is one of the most efficient, effective and logical laws aimed at protecting the environment and aiding federal agencies in making decisions. It requires scrutiny of any government plan and that is all we ask. This is a great law. We do not want to see it changed.

15. I. M. Rice, Trinity Improvement Association.
(1) Speculation has no place in agency analysis; forecasts based on best available data and made by competent and unbiased planners are useful in developing a course of action.
(2) A basic rule of research is to not try to push the conclusions beyond the available evidence. The investigator should inform the decision-maker as to the facts and the uncertainities but not try to force a conclusion that is not warranted by the evidence.
(3) The regulation does go beyond the rule of reason to the extent that unwarranted importance seems to be accorded the worst case situation.
(4) A threshold should not be established. The suggestion reflects the desire of some to develop a recipe to substitute for experience and reasoning, which is sometimes called "cook book engineering".
(5) "Worst case" is not useful. What would be most useful is a description of the most probable results of the proposed action, supplemented with a discussion of the uncertainties and risk factors involved.

16. Laurie Fowler, Legal Environmental Assistance Foundation (LEAF).
(4) "The suggestion of creating a threshold of probability or foreseeability to trigger a worst-case analysis is a dangerous one. If an impact is clearly foreseeable, obviously an agency will avoid it. It is those unlikely, or highly improbable, but severe impact events (such as . . . Three Mile Island and . . .Bhopal) that the worst-case analysis addresses. In order to make a reasoned choice of possible alternatives, Federal agencis must be aware of the consequnces of proceeding in the face of scientific uncertainty."

Other comments: It is our opinion that no amendments should be made to the regulation. As currently worded and interpreted by the courts, the regulation's purpose and requirements are unequivocably clear. It is most important to note that the regulation is not an innovation of the CEQ; rather it is a codification of early NEPA case law.

17. Larry Glass for Safe Alternatives for our Forest Environment and Phil Towle for South Fork Mountain Defense Committee.
(1) "IF an agency proposes an action AND the agency studies the environmental effects of that action AND the agency finds incomplete/unavailable information and/or scientific uncertainty and/or information gaps, THEN the agency must DISCLOSE these facts AND FORECAST or SPECULATE

about ALL POSSIBLE environmental effects REGARDLESS of their probability.
(2) Responsible forecasting requires full and complete analysis which must clearly state the type and extent of the incomplete/unavailable information, scientific uncertainty and/or information gaps; the need for action in the face of uncertainty; all of the possible effects, including cumulative effects; a thorough and complete analysis of all the risks, not a balancing of risks and benefits.
(3) The regulation is reasonable.
(4) The threshold standard is outlined in response to question one.
(5) "Worst case" is most appropriate. "It should be defined as the maximum damage that might possibly be caused by acting in spite of the fact that the effects are uncertain, ESPECIALLY when they are taken cumulatively."

Other comments: Losing court decisions is not sufficient reason to change regulations.

18 Ronald Zumbrun, Robin Rivett and James Burling, Pacific Legal Foundation and National Cattlemen's Association.
(1) When agencies must act with less than complete information or under conditions of scientific uncertainty, the disclosure requirement of NEPA mandates an incorporation of this uncertainty into the decision making process. To faciitate this incorporation to the fulest extent possible, courts allow agencies to confine their uncertainty disclosure to reasonable speculation.
(2) The regulation should be amended so that a risk analysis is substituted for worst case and is required if there is a reasonable possiblity of the occurrence of an event, which can be proved upon a firm evidentiary basis in the actual circumstances of the contemplated project; if there is a data base for evaluating its consequencs; and if the likelihood of the event is significantly increased by the performance of the project. Such a risk analysis should include: 1. a clear delineation of the factual environmental setting of the contemplated project; 2. an accurate assessment of the probability of the effect triggering event arising from the contemplated project; 3. a disclosure as to the availabiity or lack thereof of a data base for evaluating the consequences of the event; and 4. a demonstration of any causal nexus between the contemplated project and an increased likelihood of the effect-triggering event.
(3) The regulation should not require agencies to go beyond the rule of reason in implementing NEPA's uncertainty disclosure requirements. "Any implication that they must do so subverts the proper balancing of environmental consideration and agency functioning that NEPA envisions."
(4) The basic threshold we would suggest is outlined in the answer to #2. "In summary, where an agency is allowed to utilize its expertise, guided by the rule of reason to decide which events will be considered for analysis as to uncertain effects, the threshold problems disappears. Those events, with their uncertain effects, which under the totality of circumstances an agency reasonably believes on the basis of its expertise to be of sufficient probability to warrant analysis, will be subject to risk analysis under 40 C.F.R. 1502.22."
(5) "Worst case" is not a good choice. It has unfortunate emotional and connotative implications; it is an unwarranted deviation from case law, and it is without substantive criteria. It has also clouded the real functions of this sort of disclosure in the agency decision making process. We suggest "Risk Analysis Mandate" be used instead of "worst case".

Other comments: In the past, NEPA has required agencies to take a hard look at environmental factors, and then to act reasonably in using environmental data in reaching their decisions. Recent judicial decisions, however, focusing on this regulation, have ignored this legislatively mandated balance of environmental consideration and agency autonomy, "and have substituted for it irrational and uncontemplated requirements for assessing and evaluating purely speculative perceived environmental risks." Also, PLF previously submitted a petition regarding 40 C.F.R. 1502.22 to CEQ and urges that these comments be read in the context of that petition.

19. Kathleen Zimmerman, National Wildlife Federation.
(1) Every EIS requires both forecasting and speculatio to some degree. "The level of analysis required where scientific uncertainty exists is dependent rather on the significance of the risks involved: the higher

the probability of an event or the greater its potential environmental consequences, the more comprehensive a worst case analysis of any proposed action must be."
(2) It is difficult, if not impossible, to rigidly structure the type of analysis required. The rules should focus on when the analysis is needed, and the nature of the information the analysis should produce.
(3) The present rule "provides for a reasoned approach for agencies proceeding in the face of uncertainty, for full consideration and disclosure of potential significant environmental effects."
(4) NEPA sets the threshold standard by requiring agencies to explore all significant effects of their actions.
(5) "Worst case" is one possible term of art for this type of risk assessement. Now that the scientific community as well as federal agencies are familiar with the term, a name change might only produce confusion.

Other comments: "NWF believes that the 'worst case analysis' provision of the CEQ regulations . . . is extremely important, and that poor past performance by federal agencies in applying this provision demonstrates a need for greater enforcement of the existing regulation, rather than a weakening amendment. . . . The worst case analysis is not intended to be an academic exercise. The analysis goes hand in hand with NEPA"s requirement that decisionmakers consider alternatives to their actions which might reduce or eliminate potential environmental impacts. A worst case analysis which identified a low probabiity risk of a catastrophic leak forom a chemical plant might, for example, prompt the decisionmaker to mandate certain design changes in the plant. Or, it might result in a decision to locate the plant in a less populated area. Many such mitigation alternatives might be implemented at little or no cost if the potential risks are identified in a WCA early in the design of a project."

The addtion of a probability threshold would suggest that a federal agency need only satisfy itself that an event is unlikely to ignore all possible consequences of its decision no matter how catastrophic those consequences might be. The requirement of the present regulations fully comports with the rule of reason applicable to EIS's. An EIS need not concern itself with factors which have nothing to do with the actual circumstances of the proposed project or disasters the likelihood of which will not in any way be increased by carrying out the project. "However, an EIS must alert the decisionmaker and the public to the potential for low probabiity, catastrophic events; such notice may well assist in minimizing the probability or risk of harm."

20. Leslie Steial, South Feather Watershed Council. "We feel the regulation as it now exists is fine and is good for groups such as ours. We wish the regulation to be left alone."

21. William Hohmann, Colonia Solana Homeowners Association. The worst case analyses should continue, but should not require the expenditure of an unreasonable amount of funds. However, they should be conducted in a thorough and thoughtful manner.
(4) The worst case scenarios should contain threshold standards.

22. Forty-one signatures on a "Petition to Retain NEPA Regulation 102.22 As Is". (envelope from the Northcoast Envrionmental Center, Arcata, California.) The regulation is adequate as written and requires no further definition or limitation. It is functional and vitally important in protecting the human environment. Also object to timing of notice before holiday.

23. Charles Sheroke, Citizens for Environmental Quality, Asotin, Washington.
(1) A good or adequate assessment should cover the entire spectrum -- the least harmful, the worst case, and what the federal experts project to be the msot ikely effect.
(2) "If the effects of a propposed action are uncertain, then all factors or possible consequences must be weighed. . . The significance of the worst case is that you can not rule it out, if you do not know whether the worst case will or wil not occur."
(3) The regulation does not require federal agencies to go beyond the rule of reason. It is not reasonable to exclude a worst case, if hte possibiity exists for its occurrence.
(4) CEQ should not set threshold standards. "The problem with imposing a threshold standard is the possible arbitrary nature of such a standard.

Even when such standards are rationally and impartially promulgated many federal officials/agencies tend to improperly restrict their scope."
(5) "Worst case" is appropriate and should be defined as any harmful or deleterious effect which should/could/might occur should the program be implemented.

Other comments: NEPA, w/the CEO regulations, is probably the most efficient, effective and logical enactment aimed at protecting the environment. The worst case analysis regulation is vital to taking the "hard look" required by agencies.

24. Ray Leonard, Water Resources Congress.
(1) Forecasts are useful in developing a course of action when based on best available data and originated by competent planners. Speculation, on the other hand, implies risk taking and should not be used in this instance.
(2) A competent and unbiased planner presents to the decisionmaker the facts and the uncertainties, but he should not try to push conclusions beyond available evidence.
(3) The regulation places too much emphasis on the worst case, and does go beyond the rule of reason.
(4) No thresholds - the three suggested thresholds reflect the preformed judgments of the person who proposed them. The competent and unbiased planner needs no other tools besides reason and experience.
(5) The term "worst case" should be discarded. Instead, we suggest using "probable result" which would present the proposed action incorporating a presentation of the uncertainities and risks involved.

25. Ron Guenther, Sierra Club - Redwood Chapter.
The regulation is adequate as written and requires no further definition or limitations. We have had favorable experiences with the regulation. We also object to the timing of the notice, and request and extension of the timing period until March 31, 1985.

26. Dan Peterson, Gulf & Great Plains Legal Foundation.
(1) It is reasonable to require that an effort be made to present decision-makers with a forecast of any consequences which are reasonably forseeable, when information or scientific knowledge are imperfect. But the key should be whether the forecast will aid the decisionmaker, which the current regulation does not adequately address. Instead of informing the decision-maker as to the probable environmental consequencs of his decision, the worst case tells him only what is least likely to happen. Additionally, any such analysis should be based on credible science, and the current regulation does not require this.
(2) Any requirement for such a forecast should only be imposed when there are solid, relevant and rational grounds for making such a forecast.
(3) The regulation as written goes well beyond the rule of reason, as did the 1981 guidance in which CEQ stated that the worst case analysis must include all known possible environmental consequences of agency action.
(4) We believe a threshold test should be created which includes all three of the standards mentioned in the ANPRM. The three factors cannot be isolated; for example, the severity of consequences and the probability of those conseuqneces must always be linked in evaluating environmental impact. We suggest as a possible solution the elimination of the "worst case" requirement and the substitution of the threshold embodying the three factors mentioned in the ANPRM (include sample draft).
(5) "Worst case" is not appropriate. It can be used to mislead the public, affected groups, or Congress. Requiring the agency to publish an apocalyptic scenario could also make it very difficult for the agency to later approve the project. Further, it can usually result in a "built-in" deficiency in an EIS, inviting litigation, delay, and possible termination of the project. It will always be possible to come up with a worse "worst case". Instead, we suggest possibly "reasonable probability analysis."

27. Christine Luboff, Western Washington Toxics Coalition.
(1) If scientific uncertainty or missing information in relation to a particular proposal are large, then it would seem most reasonable to present the fact that it is impsosible to make any realistic assumptions about potential impacts, and thus, this option hould not be considered as a reasonable alternative. Filling the data gaps is more important than speculating. Where scientific uncertainty or missing information are less substantial and there is a related data base that can be used for

extrapolation, then the concept of worst case can be of some use. However, the speculation must be realistic.
(2) Alternatives should be clearly laid out, with the researched literature clearly presented, the data gaps identified and the choices and their concomitant risks compared in a straightforward manner. The fact this does not happen now is not because of regulatory defects, but because of lack of effort.
(3) Presumably, the courts will continue to decide what is within the rule of reason.
(4) We are absolutely opposed to a threshold standard of any kind.
(5) The term "worst case" is absolutely appropriate. The intention is to identify the worst possible thing that could happen and for decisions to be made that understand this. To change the term is to change the concept.

28. Phyllis Cribby, Southern Oregon Citizens Against Toxic Sprays.
(1) We do not know how the regulation could be more specific in stating when such analysis must be done. However, following the logic and intent of NEPA, the extent to which an agency must engage in forecasting and speculation is governed by uncertainty identified and concerns raised during the planning, scoping and review process.
(2) The most useful and understandable information would be contained in an initial description of the data gaps and their relevance to the decision to be made. In the process of setting that information into a worst case analysis, both risks and possibilities for mitigation should be clarified. The structure of such an analysis should incorporate operational experience, rather than be built on best management practices. Extreme and impossible scenarios (such as a person drinking gallons of contaminated water in one day) should not be used these analyses are not helpful.
(3) The rule of reason is a correct standard, but cannot be used to mean that only provable probabilities trigger the regulation.
(4) The possibility of severe consequences is already the threshold standard for the entire regulation. We do not see how scientific credibility could be a threshold - it is important to all analyses. We do not believe that probability can be used as a threshold. The only threshold that should be used is "adequate information."
(5) "Worst case" is an appropriate term, but the title is not important as long as the substance of the regulation is followed. One problem we believe agencies are having is that they are not following the first part of the regulation, i.e., identification and disclosure of data gaps. These steps must be followed or the regulation will inevitably be violated.

Other comments: Much of the "misunderstanding and confusion" about the regulation is being perpetrated and perpetuated by misrepresentations or misinterpretations of the pertinent case. The SOCATS case is being commented on by persons who have never seen the record. The "problems" which federal agencies have had in complying with the regulation can be remedied by simply addressing the regulation as a whole and through honesty and candor. Before any amendment is considered, the need for it should be thoroughly established. Additionally, inquired about the proposed Advisory Committee - what to it? Also, incorporate by reference their comments of October 8, 1983, on the proposed guidance.

29. Frederick Middleton, III, Sierra Club Legal Defense Fund, Inc.
(1) A federal agency must engage in forecasting or reasonable speculation when the information that cannot be obtained is significant or important to the decision; in other words, NEPA requires a forecast of potential harm when information is missing that a reasonable man would want to consider in his decision.

Although we do not believe that any change is needed in the regulation, we do suggest new language to remove the inconsistency in subsection (b)(1) and (2).
(4) No threshold of severe consequences or probability is appropraite. Please refer to our comments of October 16, 1983, in this regard. If you are concerned with reasonable limits on the requirements of a worst case, the Sigler court made it clear that the possibility of a worst case must be grounded in historical or scientific fact or credible scientific opinion, and that information must be available upon which a meaningful discussion of the effects of a worst case could be made.
(5) The analysis must address the risk and severity of all potential adverse impacts, not just the worst case. However, we have learned that the worst case is often of great concern to the public - and should be to the decisionmaker - and requires special attention.

Other comments: The objectives of the regulation are : 1) the disclosure of uncertainty, and 2) forecasting to the best of an agency's ability. Many of the current cases deal with the first objective - i.e., the agency's have not been willing to disclose uncertainty. We do not see how this problem can be solved by changing the regulation. We believe that your effort is well-intentioned but misguided and goes primarily to the second objective. That will still not solve the problem of agencies attempting to cover up the uncertainty or data gaps about their proposed action.

30. Norma Grier, Northwest Coalition for Alternatives to Pesticides.
(1) NEPA requires full disclosure of information or the lack of information concerning the potential impacts of proposed actions. Scientific uncertainty must be considered when it is uncovered by the agency or raised in scoping or in comments by interested parties. An agency needs to be honest about the information base for their decision. The regulation's emphasis on a complete data base as possible is essential for protection of public health and environmental quality.
(2) The analysis should be structured so that alternatives may be compared at the end of the analysis; a reader can determine which alternatives have the least and the most information; the concerns are clearly identified in the analysis; and non-quantifiable values are identified.
(3) It is reasonable for an agency to include in its analysis the consequences of proceeding in the face of uncertainty both for the effects of the action and the likelihood of the events occuring. For example, if a pesticide is proposed for use for which no cancer tests have been performed, then it is reasonable for the agency to consider that people may get cancer. They should also consider that there is uncertainty in the scientific community that any exposure to a potential carcinogen is a risk.
(4) A threshold standard is built into the current regulation and that standard should be retained.
(5) NEPA must encourage informed decisionmaking and consideration of uncertainty by an agency must be understandable and accessible. Retention of the current term "worst case" would best achieve that end.

Attachment: "Risk Analysis", a NCAP Position Document.

31. Fred Hoerger, Amerian Industrial Health Council.
We believe that the general thrust of the present regulation is correct, but that it puts no bounds on speculative imagination nor does it require that the analyses be soundly founded on fact. It is appropriate that scientific evaluation included in the analyses is reasonably forseeable based on existing facts. It would be appropriate to amend the regulation to specify that it does not require analysis of speculative potential adverse consequences. Such speculation serves neither the decisionmaker nor the public.

32. Twenty-three names on a Petition from the California Coalition for Alternatives to Pesticides. The regulation is adequate and needs no amendment. It is vitally important in protecting the environment. Also protest the notice being issued during the holiday season.

33. Forty-three names on a Petition from the San Juan Ridge Environmental Council. The regulation is adequate and needs no amendment. It is vitally important to the protection of the environment. Also protest the notice being issued during the holiday season.

Congressional/Legislative Responses

1. James B. Corlett, Western States Legislative Forestry Task Force.
   (1) Only when thorough examination of documented, research-based scientific evidence by trained and experience officials yields continued scientific uncertainty that is crucial to decision making should an agency engage in forecasting or speculation. "Crucial to making a decision" means that the responsible official lacks any other basis such as professional judgment or experienced related knowledge in similar situations on which to decide. "Scientific uncertainty" means that the probability of a certain effect following an action cannot be determined by available scientific means with acceptable levels of confidence.
   (2) An analysis should be related to levels of risk; risk analysis papers should be read.
   (3) We believe the courts have interpreted the regulation to mean that a worst case analysis is required as a consequence of any degree of uncertainty, thus going beyond the rule of reason.
   (4) Threshold standards should be established in relationship to levels of risk. Provision should be included for consideration of experienced knowledge and professional judgment of officials.
   (5) "Worst case" is not appropriate. We suggest "risk analysis".

2. Congressman Denny Smith, Fifth District, Oregon.
   (1 & 2). "I agree that agencies, in preparing environmental impact statements, should exercise reasonable speculation to determine what events might reasonably be expected to trigger uncertain and potentially adverse impacts on the environment. A worst case analysis, then, should be made only when there is a reasonable probability, based on hard data from the actual circumstances of a proposed project, that a worst case event can happen."
   (3) Federal agencies should work within the rule of reason.
   (4) "I disagree with those who would propose a threshold standard, applied either to the probability of some event or to the severity of its consequent impacts. More than in any other situation, it is the low probality/high catastrophe event that requires agencies to have the discretion afforded under the rule of reason standard. Iron-clad numerical thresholds might inhibit reasonable speculation where it is needed most."

   Other comments: "Workable balance must be returned to regulations governing agency disclosure and worst case analysis in EIS(s)."

Individual Commentators:

1. Lynton K. Caldwell, Professor of Political Science, Indiana University: ". . . I do not see a persuasive case for a new rule possibly restricting worst case analysis." (1) There are many circumstances, impractical to anticipate, in which federal agencies must engage in forecasting or speculation. (2) The present regulations provide sufficient basis for reasonable forecasting in the face of scientific uncertainty. (3) The regulation does not require agencies to go beyond the rule of reason. (4) Threshold standards would be useful administrative devices if they could be identified and reliably applied. (5) The worst case concept is sufficiently common to justify its use. It refers to an impact having the most disasterous or damaging effect upon people, property, or nature.

2. Baruch Fischoff, Research Associate, Decision Research, a Branch of Perceptronics. It is extremely important to define the objectives that a worst case analysis is supposed to serve; the one worst case analysis that I have looked at suffered from the absence of a clear conceptualization of what it was meant to accomplish. Presently, the objectives seem to be:
   a. Encouraging and rewarding the candid summary of available scientific knowledge;
   b. Facilitating a fair appraisal of the definitiveness of currently available scientific knowledge;
   c. Exposing the logic underlying the policy decisions based upon that knowledge;
   d. Encouraging and rewarding the cost-effective production of additional scientific knowledge;

e. Separating the functions of scientific analysis and policy making in the risk management process.

(1) "A federal agency should always confront the scientific uncertainty or gaps in information concerning the environmental effects of a proposed action." There are widely accepted procedures for rendering such judgments, but it should not be called "forecasting or speculation" which suggests a lack of discipline.

(2) Uncertainty should be estimated and expressed in keeping with standard scientific practice. A simple decision-theory perspective should be used to show policy-makers and other interested parties how sensitive decisions are to different kinds of uncertainty and what are the opportunities for reducing that uncertainty in a cost-effective way.

(3) The current regulation is consistent with the rule of reason, at least as defined by decision theory.

(4) I would not attempt to answer the threshold analysis question in these time constraints; however, it seems very unlikely that such an effort would point to the viability of a simple rule such as the thresholds suggested in the notice. Any procedure along this line, however, should reward the creation of knowledge, rather than the maintenance of ignorance.

(5) The term "worst case" conjures up associations of irresponsible fear mongering and detracts from the ultimate aim of the regulation. "It is my understanding of the historical development of the term that it arouse from a concern that policy-makers were ignoring the uncertainties surrounding existing evidence (or not being presented with those uncertainties by their scientific informants). Assuming that a process was developed that allayed those fears, terms such as 'uncertainty analysis' or 'decision analysis' might be more appropriate."

Other comments: It is a hallmark of sound scientific practice that uncertainty be acknowledged. Equal attention should be given to the uncertainties surrounding the benefits arising from proposed action. Also enclosed "Conceptual Framework for Regulatory Benefits Assessment", Chapter IV of Handbook of Benefits Assessment, prepared by the National Science Foundation for the Office of Management and Budget.

3. James Van Ness. (1) The current regulatory "trigger" is entirely appropriate and well serves NEPA's "full disclosure" function. "Simply because the scientific community cannot yet predict the consequences of the proposed action w/scientific certainty does not diminish the need for thoughtful reflection prior to action. Under conditions of uncertainty, prudence may well caution postponing an action until the scientific community catches up with technology. Absent the requirement for a WCA, significant---albeit minority--segment of the scientific community may be effectively silenced to mankind's everlasting regret."

(2) The current regulation is sufficient. In the absence of a generally-accepted methodology for analysis, the prudent course of action would be to assume the most pessimistic predictions of that portion of the scientific community deemed most conservative yet still credible, and predict the worst case consequences that would follow.

(3) In the context of the regulation, the rule of reason is that a WCA must be done about highly improbable--but not inconceivable--consequences when those consequences may have a potentially catastrophic impact on the environment. The rule of reason in such circumstances serves primarily to relax the standards courts should apply when judging the sufficiency of a necssarily imprecise WCA, not to foreclose the need for the analysis altogether.

(4) The Fifth Circuit Court of Appeals discussion in Sierra Club v. Sigler regarding the necessity for credible evidence to exist that the worst case event could occur and cause significant environmental damage is sufficient.

(5) There are good reasons to eliminate the phrase "worst case analysis" which connotes agency-endorsed "doomsday predictions." Suggests the use of a less inflammatory phrase, such as "environmental risk analysis."

Other comments: The present regulation needs to be clarified, but not drastically altered. It provides several benefits, such as encouraging the agencies to be more conservative in their decisions when uncertainty is involved and perhaps contributing to the advancement of science.

4. Harriet Witt Miller. Please protect the regulation. Just because an event has a low probability of occurring does not mean that its impact is in any way lessened.

5. John Osborn, M.D. Modification of language pertaining to worst case analysis could have "tremendous and deleterious impacts on National Forest System fisheries and wildlife. For this reason, I oppose any such changes in 'worst case analysis.'"

6. John Buckley. The current regulation is reasonable and protects the human environment.
   (1) An agency should speculate whenever scientific uncertainty logically leads to a reasonable possibility of major significant adverse effects. The speculation or forecast should include the full range of possible consequences.
   (2) Any analysis should be structured in terms of "most likely", "likely", and "possible".
   (3) Federal agencies should go extremes in regards to discovering and broadcasting potential significant adverse effects even beyond the rule of reason. The public should be totally informed as to even remote possibilities.
   (5) Worst case is an appropriate term.

7. Paul Slovic, Research Associate, Decision Research, A Branch of Perceptronics.
   (1) In the face of risk and uncertainty, important agency actions should always be guided by analysis; however, that analysis should be risk analysis or risk assessment, not worst case analysis.
   (2) Risk analysis, properly conducted, provides a framework for responsibly characterizing the magnitude and likelihood of possible adverse consequences of an agency action.
   (4) Risk analysis does not require that a threshold be established. Instead, the analysis attempts to describe the full set of possible outcomes and the uncertainties associated with those outcomes based on theory, data, and informed opinion. The decision maker can then decide how to weigh the more extreme possible outcomes. The analysis would also have information about less extreme but more likely outcomes.
   (5) "Worst case" is not an appropriate term. "It has no defensible rationale or procedures. It is little more than a catchy phrase, springing full blown into regulation and use without any discernible link to the disciplines that have devoted so much thought and effort toward developing rational ways to cope with problems of uncertainty. It is, therefore, not surprising that no one knows how to do a worst case analysis and that agency attempts have been rejected repeatedly in court. Amending 40 C.F.R. 1502.22 is unlikely to improve this unsatisfactory state of affairs unless it takes advantage of the insights and approaches that have developed within the framework of risk analysis." The most appropriate term is risk analysis or risk assessment.

   Other comments: urges establishment of advisory guidance to provide guidance regarding changes in the regulation.

8. John C. Barber, Ph.D., Consultant. (1) "There will always be some scientific uncertainty and information gaps about any proposed action. The agency should be obligated to speculate or forecast only when the proposed action is experimental or when there is to be a substantial deviation from normal procedures based on research and experience."
   The fundamental problem is the courts' refusal to accept the validity of EPA's registration and labeling of pesticides. Supports legislative action to accomplish this goal.
   (2) The analysis should include the proposed work plan, a probability of exposure and a best estimate of the consequences of such exposure based on available scientific evidence. If the work takes place in an area closed to the public, the analysis should concern only the workers involved. In the case of pesticides, prior experience and safety records should be provided.
   (3) The current regulation places an undue burden on agencies; it is ambiguous in its terms.
   (4) While they are hard to define, thresholds would be useful from an administrator's viewpoint.
   (5) "Worst case" is an inappropriate term. The regulation should simply call for a benefit/risk analysis.

9. Toni K. Ristau.
(1) There are two related problems - one involves speculation on the exact shape and scope of the proposed action, and the other involves the exact nature of environmental consequences expected from an unknown or ill-defined technology.
(2) One possible solution is to concentrate analytical efforts on strategies where information is available or data can be obtained, rather than making predictions. Worst case judgments may still be required, but the worst case judgment is about the sensitivity of resources that have, through the analytical process, been determined to be an important component of the environment where the proposed action will occur. This analytical approach shifts the focus away from heavy reliance on forecasting to the formulation of alternative resource protection strategies.
(3) Although the regulation on its face does not go beyond the rule of reason, there is an interpretative problem. Perhaps the best solution would be to add further refinements to guidance on how to do such an analysis.
(4) The use of worst case analyses could be limited to assumptions about the nature and the sensitivity of resources deemed worthy of protection; it would not be utilized to speculate upon the shape of technology or development, or about the possibility of unknown and presently unknowable environmental effects. However, the adoption of a rigid threshold does not appear workable. There would always remain room for dispute about whether the threshold had been reached.
(5) Because of the semantic problems, "worst case" should probably be eliminated as a term. Instead, terminology conveying the sense of "an upper analytical bound for protection scenarios" could be substituted.
Also attached a paper, "Tar Sands: Problems in Environmental Assessment and Management in a Developing Industry."

Other comments: "The regulation has posed a perennial problem of interpretation and compliance by persons who, like myself, perform NEPA compliance analyses. . . . though the existing regulation may be flawed, I would propose leaving it in place until some of the questions you have raised (and others have asked), as well as some of the analytical difficulties related to performing a meaningful 'worst case analysis', can be put to rest. . . . perhaps the best short-term solution would be to experiment with application of one or mpre proposed analytical approaches." A balance should be struck between the chilling effect of unbridled speculation and the possibility of unforeseen environmental damage.

10. Joseph and Susan Bower. "We urge you to leave the regulation as it is. It is clear, practical and needed. . . . Remember Bhopal India did not have a worst case analysis."

11. Don Cornelius, M.D. "What CEQ is attempting to do is frightening. The idea of watering down the 'worst case' portion of NEPA is clearly not in the best interest of those of us who live in areas where these chemicals are used in large quantities. . . Bhopal is just one case. How many more will we need?"

12 Michael Newton, Professor, Forest Ecology, Oregon State University. When an EIS is required and when a worst case analysis is necessary part of the EIS, the rules for preparation and legally enforceable contents should be clear and reflect CEQ's intent. It would be reasonable to include in a worst case analysis any alternative proposal for executing the program that has a potentially greater impact on human health or the general environment than the subject being challenged.

13. Susan Thomas, Instructor of Environmental Protection Management.
(1) "Reasonably foreseeable" is still useful; each case is always going to be different and there is no need to quantify this requirement.
(2) Publish good ideas as guidance (for how-to-do analysis) rather than as a regulatory change. This may be the first time CEQ has addressed 102(2)(B) of NEPA!
(3) No, the regulation doesn't go beyond the rule of reason.
(5) "Worst case" is a perfectly serviceable term.

Other comments: I do not believe that a concrete threshold to define probability or some other threshold would be useful. What is needed is some statement by CEQ that another agency's raw data may be used in a worst-case analysis (but not replace it), and that the analysis itself should not require exorbitant expenditure to comply with the law. Provides suggested regulatory changes to address both of these problems.

14. Harry Voight, Partner, LeBoeuf, Lamb, Leiby & MacRae, (apparently for the firm).
(1) An agency need engage in speculation and forecasting only when significant environmental effects are credible, and the analysis can be conducted and structured so that it will aid in a reasoned choice among alternatives.
(2) Agencies must be given significant latitude in determining how to structure the analysis. CEQ should provide guidance in this area, but not a rigid set of procedures. The guidance should address such factors as the desirability of using conservative or bounding estimates, the need for a statement of the agency's belief concerning the degree to which the results obtained are representative of expected impacts, and the consideration of mitigation measures.
(3) The primary problem with the regulation is that it is unclear what it requires and this uncertainty has forced agencies to go beyond the rule of reason and has opened the floodgates to litigation. CEQ should make clear that NEPA does not require a worst-case analysis for every proposed agency action or anytime there is uncertainty or lack of scientific information.
(4) We believe that CEQ should establish a threshold standard that would trigger the need to prepare an analysis of possible adverse impacts, and that significant discretion should be given to the agencies to determine whether that threshold is triggered. Examples of relevant factors which should be considered in determining if such an analysis is needed are: the base of historical and scientific knowledge surrounding the uncertainty; the credibility and risk of a "worst case" accident; the feasibility of conducting the analysis in light of existing scientific and technical knowledge and capabilities; and the costs of obtaining unknown information to conduct the analysis and the benefits of the analysis in terms of its relevance to the decision making process.
(5) "Worst case" is not an appropriate term; in many cases, it will cause more apprehension and fear in the public than warranted. We suggested that CEQ not devise a label for an analysis of possible adverse impacts where there is a gap in information or a scientific uncertainty.

Other comments: include proposed regulatory change based on above comments.

15. Dr. Miller B. Spangler.
(1) When preparing assessments of risks or forecasts of future risk levels and non-safety effects on the human environment, an agency should engage in speculation when confronted with scientific uncertainty, excluding scenarios of insignificant probability and whenever there is an insufficiently credible rationality and substantiating evidence for responsible conjecture on such scenarios.
(2) Forecasting and speculation must be distinguished. Suggestions are:
---examine historical data to identify a relevant set of causal factors which could potentially aid in forecasting environmental effects;
---through the use of scientific insight and responsible imagination, add to this list potentially emergent causal factors and delete any disappearing causal factors;
---reach a decision as to what useful scenarios might be constructed surrounding these causal factors to aid either risk assessment or the forecasting of relevant events or effects of the proposed action.
---decide which assessment or forecasting methodologies are most appropriately employed, considering cost, tradeoffs, etc.;
---decide on the most effective means of presenting the analysis.
(3) At the present time, it is not clear to what extent agencies may be required, by reason of the regulation, to evaluate certain types of low probability/high impact events which under the rule of reason would not otherwise require consideration because the likelihood that those events would occur is so remote as to render them insignificant.
(4) It does not appear practical to set threshold values for consequences that are not amenable to quantification. However, the most important concept of the regulatory concept of setting threshold standards is the theory of de minimis probability applied by practitioners of probabilistic risk assessment.
(5) I feel rather strongly that this term should be stricken, and suggest in its place "low probability/high-consequence risk analysis." The term "worst case" does not suit the special needs of regulatory decision making

since it does not discriminate between situations involving high probabilities and moderate-to-high consequences and those involving low-to-moderate probabilities and high consequences. Additionally, it is an emotionally prejudicial term. Analysis of low-probability/high-consequence risk scenarios is the most rational means of determining whether previous design conservatisms might have been excessive or whether additional modifications are necessary, thus safeguarding against a repeat of such disasters as Three Mile Island and Bhopal.

Other comments: Proposed amendment. Dr. Spangler's comments are extremely voluminous, and are not amenable to brief summarization. Aside from detailed to the ANPRM questions, he includes general comments on the regulation and related issues; a discussion of the relevancy of the NRC's experience in treating low-probability/high-consequence events in the face of uncertainty; recommendations, and copies of fifteen articles and memos regarding risk assessment and related problems.

16. Nicholas Sakhnovsky. The reference to costs of analysis in the current regulation is vague and non-specific. I proposed replacing the phrase "exorbitant" with "in excess of __% of the total costs of the estimated costs of the proposal".

17. Paul Paulsen. "I have no objection to the Forest Service's use of herbicides on public land. . . I believe herbicides to be one of the cheapest and most effective tool to improve these lands."

18. Robert Stanley Lowe.
    (1) "To require an agency of the government to engage in anything so hypothetical as forecasting or speculating about scientific matters under any and all circumstances places the agency in a ridiculous position and impairs is credibility.
    (2) "The most intelligent answer is the obvious one that the analysis should only be predicated upon those things that are sufficiently known to permit the making of responsible statements with a reasonable degree of scientific certainty.
    (3) "In my judgment, the analysis called for by the current language of Section 1502.22 which places undue emphasis on filling gaps in information with unreliable speculation as opposed to the real substance of solid information that is available compels federal agencies to go beyond 'the rule of reason.'"
    (4) No, as stated previously, there is never any reason for dealing with speculation in the first place.
    (5) The term "worst case" is not appropriate.

19. Thomas Stokely. "I firmly believe that elimination of the existing regulation will result in short sighted, biased and economical decisions by federal decisionmakers." Elimination of it will result in major mistakes, such as those shown by the use of Agent Orange in Vietnam and the recent disaster in Bhopal. Pesticide spills are already a problem in my area. Elimination of the worst case analysis will cause a feeling of helplessness and anger and lead to poor decisionmaking, and possibly, a backlash.

FEDERAL AGENCIES

1. Loy Hayes, Jr. Federal Bureau of Prisons, Department of Justice.
(1) When those gaps in information deal with areas which will directly affect the physical quality of human life, e.g., air, soil, water. Gaps in social factors should only be forecast if direct effects will likelly result from the project.
(2) A risk-return analysis may be used to analyze otherwise unquantifiable aspects in the proposal (similiar to a cost-benefit analysis).
(3) No - rule of reason should apply.
(4) No; any threshold would be diffficult to define or apply; the agency's judgment is the most informed concerning any given project.
(5) Yes; "worst case" adequately describes the least desirable result or occurrence which might arise from a given set of circumstances.

2. Charles Lauer, Office of Justice Programs, Department of Justice. No comment.

3. George Baumlui, Principal Engineer, International Boundary and Water Commission. (1) Speculation without data should not be done; forecasting should only be done for the near future when an adequate data base exists.
(2) Analyze on the basis of facts known today and those that can be reliably forecast over the near future. Mitigate when appropriate and structure project or actions to make future assessments of impacts when reliable data are known.
(3) Rule of reason should apply; it does not in current regulation.
(4) No threshold should be set; analyses should be made on a case-by-case basis.
(5) The term "worst case" is appropriate. It should be defined as those near future conditions which would result in the most adverse environmental impact.

4. Stephen Margolis, Ph.D., Chief, Environmental Affairs Group, Environmental Health Services Division, Center for Environmental Health, Public Health Service, Center for Disease Control, Department of Health and Human Services.
(1) With regard to the circumstances for conducting a worst case analysis, the environmental effects (direct or indirect) should be significant, adverse, and reasonably foreseeable. The extent to which an agency should engage in conducting a worst case anlaysis should depend primarily upon the importance of the information and whether the alternative is likely to be selected. If the risk and severity of the possible adverse impacts are significant and their occurrence is highly probable, a worst case analysis should be included in the EIS. Costs should not exclude a worst case analysis where public health may be endangered by the proposed action.
(2) A matrix could be used to compare alternatives for summarizing worst case effects and known negative and positive environmental impacts. A decision-tree approach with a matrix table summary could be used. However, the question of methods and approaches should be left up to the EIS preparer.
(3) It should not require agencies to go beyond the rule of reason.
(4) Threshold standards may be helpful, but they should be expressed with qualitative criteria (e.g., potential cancer risks, potential exposure to toxic and hazardous agents, etc.) rather than quantitative.
(5) The term worst case is satisfactory; it should represent a reasonable projection of the worst possible consequences of a given impact.

5. William Sullivan, Director, Office of Envirnmental Affairs, Veterans Administration.
(1) The guiding judicial principles in NEPA appear to be a mandate for consideration and full disclosure to the public of the potential consequences of agency decisions; in particular, the unknown aspects, when they are essential and important. The task then becomes one of quantifying the risk to whatever benefits are to be gained.
(2) "The analysis structure, as interpreted by CEQ, alludes to a range of events considering various magnitudes of impact. This Agency finds no problem with that approach." It must be governed by the rule of reason.
(3) "This Agency's consideration of the regulation indicates CEQ's provision for the analysis is consistent with the legislative history of NEPA and with NEPA case law."
(4) The position of the VA is that the severity of consequence would

be a more justifiable threshold than the others mentioned in the ANPRM.
(5) "Worst case" does cause confusion and infers one set of circumstances; perhaps a term such as "analysis of uncertain effects" is more descriptive of the intent.

6. Grant Reynolds, Department of the Air Force.
(1) Decision-makers are always confronted w/some scientific uncertainty and gaps in information. We do not think an agency should engage in outright speculation in predicting environmental impacts. "The enumeration and specificity of the potential impacts should be detailed enough to adeuately describre the reasonably anticipated results but they must not be required to be so exhaustive as to blur the truly significant and likely impacts from the remote possibilities. The case law rule prior to adoption of 1502.22, that NEPA does not require consideration of 'remote and speculative' effects, was a good one should be reinstated."

Suggest keeping first sentence of 1502.22 (full disclosure sentence) intact; deleting (a) and (b) and adding the following sentence after the first sentence, "Where there is disagreement among scientists about a potentially significant adverse impact, responsible opposing scientific views shall be set out in the EIS along with the agency's analysis."
(2) Speculation, either pessimistic of optimistic, has no place in an EIS. We do not know how to forecast that which is by definitin unknown or uncertain; where reasonable forecasting of an effect is possible, the only precaution called for is state the degree of uncertainty. An EIS should carefully define the uncertainty. its significance, and any scientific disagreements about it.
(3) The current regulation repeals the rule of reasons. Judicial decisions have made this clear. "Unbridled conjecture will serve neither the environment nor the taxpayers. Our proposal, deletion of 1502.22(a) and (b) specifically reinstates the rule of reason by emphasizing that the requirement to describe uncertainty or information gaps only applies 'when the agency is evaluating significant adverse effects . . ."
(4) If the requirement for worst case analysis is retained, we think that the establishment of a threshold mechanism would be an "illusory panacea. It would simply add another broad concept that would be meaningless until interpreted by the courts. The broad range of agency actions requiring EIS's makes a sharp definition of the threshold impossible. An agency's decision regarding EIS content, including when and 'how to prepare a worst case analysis,' should continue to be based on the rule of what is reasonable and significant; that is, the 'rule of reason'. Scientific uncertainty 'should be acknowledged and the EIS should summarize disputes within the scientific community. Such 'full disclosure' would serve to prevent too much emphasis being placed on overly pessimistic asumptions offered by a limited part of the scientific community."

EIS could conceivably contain more than one worst case. Moreover, since NEPA is a continuous process, if any new, significant circumstances or information relevant to environmental concerns become available, the action would have to be reevaluated based on supplemental analyses.
(5) If our recommendation to delete the whole concept is not accepted, the term "worst case" should be changed. The term connotes agency-endorsed doomsday predictions, and for this reason tends to create agency resistance to the process. We suggest a phrase such as "environmental risk analysis."

The definition is more important than the name. "CEQ must provide a concrete description of a worst case analysis, or EIS's will become useless exercises in speculation. We, like many others, have some ideas on guidelines for their preparation. The professional fields of system analysis, safety analysis, and risk analysis have a lot to teach in this regard.

Other comments: This regulation represents one of the few analytic failures in otherwise excellent regulations. The regulation runs against NEPA's goal of trying to produce analyses of the real world for flesh and blood decision-makers. The key terms in the regulation are unknowable and undefinable and the very concept of worst case analysis is defined.
"We believe that the worst case analysis experiment should be terminated before it discredits serious environmental impact analysis. We say this not because we secretly wish to water down NEPA, but because we believe in it. EIS's are valuable decision-making aids. They have a powerful influence on administrative processes that would otherwise concentrate exclusively on budget and policy considerations. However, EIS's full of pessimistic

speculation about unlikely events will have little impact on the decision-
making process. They wil be discounted as lawyer's fireproofing, not
attempts to inform decision-makers and to encourage the striking of balances
between environmental effects and program benfits."

7. Richard Hoffman, Federal Energy Regulatory Commission.
(1) "An agency should not engage in excessive speculation or fictional
exercises. Reasonable forecasting or speculation should e required
whenever severe consequences such as loss of life, significant loss of
property, chronic health roblems, or significant long-term or irreparable
environmental damage may occur as a result of an action." The forecasting
should be based on reasonably probable events.
(2) The analysis should include:
---explanation of the uncertainty or data deficiency;
---description of the potential effects which lead to the decisions
to conduct the analysis;
---description of the basis for each asssumption which materially
affects the outcome of the analysis;
---list of assumptions made;
---estimated range of probability of the occurrence of the limiting
case;
---how the outcome of the analysis affects the overall environmental
analysis;
---sensitivity analysis of how the assumptions affect the overall
environmental analysis.
(3) The problem is that "worst case" by definition can go beyond the
rule of reason. The term should be changed to "worst credible
case", thus limiting the analysis to worst cases within the rule of reason.
(4) It seems unlikely that an adequate threshold could be designated.
If an attempt is made to do so, it should be specific and not become
the basis for further legal and technical disputes.
(5) The term 'worst case" is appropriate for an anlysis that defines
the extreme limit of severe impact from a proposal. However,
previous experience with worst case analyses at FERC have shown that
many of these events were actually noncredible events. As a result,
staff have decided to study ony "maximum creditle events". Other
possible terms are "worst credible case", "worst reasonable case", and
"worst case within rule of reason".
Possible definitions for any of the terms:
"The end result of an action based on the combination of
individual effects which may have a low probabiity of occurrence
but are reasonably expectable or credible", or,
A deleterious impact from a proposed action which may have a
low probability of occurrence but is possible within the realm
of reasonable expectations."

8. Richard Cornelius, Department of the Navy.
(1) Agencies should be required to engage in speculation or forecasting
only when the gaps of information are relevant to significant environmental
issues and the information which is lacking is itself important to the
decision maker because of its relation to the consequences of proceeding
with a proposal.
(2) An analysis must be based on credible scientific evidence and must
deal with likely consequencs that stem from such evidence.
(3) If recent case law is allowed to stand with no amendment to the
regulation, the answer is that the regulation does go beyond the rule of
reason
(4) Yes, a threshold standard should be established based on a combination
of scientific credibiity, severe consequence, and probability.
(5) The term "worst case" is not appropriate .

9. William Southard, Interstate Commerce Commission.
We understand the purpose of a worst case analysis to be to ensure full
public disclosure and consideration by agencies of the potentially worst
consequences of their actions when scientific uncertainities or gaps in

in available information exists. We believe that the regulation is adequate and provides reasonable guidance. In our view, a worst case analysis does not lend itself to the application of a single criterion or hard and fast thresholds. Existing case law provides sufficient guidance.

10. Adair Montgomery, National Science Foundation.
    (1) The existing regulation accomplishes this goal with sufficient opportunity for subjective judgment using such terms as "essential", "exorbitant", and "state of the art".
    (2) If there are sufficient historical cases of a similar nature, statistical analysis could be used to give an indication of probability. This is not likely to be the case if there is truly scientific uncertainty or information gaps. Possibly, one could examine projects of a similar kind but lesser risk, using different types of technologies and add levels of complexity to reach the level of the proosed action.
    (4) A single threshold is not appropriate; the relative importance of the suggested thresholds depends on the proposed action.
    (5) The concept of "worst case analysis" is appropriate, but a more understandable term would be "maximum probable (or possible) impact".

11. Jack Smith, Federal Communications Commission. no comment.

12. James Hildreth, Acting Chief, Envionment and Resource Branch, Mobile District Corps of Engineers, Department of the Army.
    (1) When sufficient data does not exist to make a credible decision of probable impacts, the agency should consider the impacts that have occurred as a result of any previous similiar action; take a reasonable scientific and economic approach to addess the unknowns, and not be required to perform studies of a research nature.
    (2) The analysis to be performed should be narrowly strutured and concentrate solely on the impact-causing agent or agents.
    (3) The existing rule of reason should be maintained.
    (4) A national threshold standard incorporating severe consequences, probability of occurrence and scientific credibility should be established.
    (5) The term "worst case" is appropriate, provided the above criteria are used.

13. Richard Broun, Director, Office of Environment and Energy, Department of Housing and Urban Development.
    (1) The circumstances warranting a worst case analysis should be treated as a judgment call to be made by the agency. There should be no additional, across-the-board rulemaking as to when an agency must engage in forecasting or speculation.
    (2) The agencies should be required to ascertain recent advances in the state-of-the-art, to review related analysis made by other agencies, and if the degree of potential hazard may be significant, to employ in the analysis 3rd party contractors or other agencies not having a vested interested in the proposed action.
    (3) In making such analyses, the agency should not go beyond reasonable expectancies and contingencies. For projects near urban areas, the possibility of continued urbanization should be carefully considered, including the viability of buffer zones for dangerous facilities.
    (4) In lieu of a fixed threshold, CEQ might provide a series of criteria which should be considered by an agency in making its judgment call as to the need for a worst case analysis.
    (5) The term "worst case" indicates the intent; however, it also indicates a sense of alarm in cases where civilization is not imperilled. Other terms which could be subsistuted include: contingent factor forecasting, contingency analysis, contingent impact analysis, low probabiity/high severity impact analysis.

14 Allan Hirsch, Director, Office of Federal Activities, U.S. Environmental Protection Agency.
    (1) We believe that forecasting is required (a) when there is a potential for significant impacts on the environment, based upon effects which can be reasonably predicted on the basis of credible scientific evidence or inference. The magnitude and severity of the potential impacts must also be weighed in deciding how to make the forecast. For example, where the potential consequnces of an event are severe or catastrophic, it may be important to forecast such events even where the probability is low. The degree of scientific consensus must be weighed against the potential

likelihood of impacts or severity of the consequences. The scoping process is a valuable means of establishing the range of potential impacts that should be addressed. The probability of such events occurring is not the only factor that should be considered in determining how to address a potential impact.

The information must be important to the decision. If the information or analysis could not reasonably affect the project decision (including project design alternatives and mitigation elements) then the analysis is not required.

Worst case analysis cannot be considered in isolation from the rest of the analysis presented in an EIS as proposed federal actions cannot be clearly separated into two discrete classes (those for which there are and are not a complete information base). The environmental impact assessment process represents a continuum of situations ranging from those involving very predictable events to those where the outcome is uncertain. Isolating the "worst case" requirement from the other analysis can cause confusion.

(2) While it is difficult to specify exact analyical structure to present forecasting in the face of scientific uncertainty or information gaps, the analysis should include identification and description of the potential adverse effects based upon appropriate scientific evidence or inferences, estimation of the magnitude or severity of those effects, estimation of the probability of the effects occurring under various scenarios (normal project operations, accidents, etc.) and characterization of the nature and extent of the uncertainties involved in estimating the risks. Agencies should make special efforts to present the analysis clearly, in realistic terms, and should identify the major assumptions used, the level of confidence in those assumptions and the error factors.

EPA has found risk asdsessment useful in its regulatory decisions.

(3) We do not think that the regulation should be read to require agencies to go beyond the rule of reason. However, some recent judicial interpretations of this section have raised concerns that in specific instances, agencies may be required to go beyond the rule of reason. Therefore, revision of this section to better reflect the rule of reason is necessary.

(4) No, thresholds should not be established. All the factors listed in the ANPRM should be considered on an interactivee basis in determining the degree and depth of analysis required.

(5) The use of the term "worst case" has created confusion. To avoid this confusion, we believe that the regulation should be revised to provide a better description of the parameters of limits of these analyses. However, it is not possible to provide a precise definition of those limits. For some specific situations, it may be appropriate to define a quantitative limit, e.g., limiting the analyses to events or impacts with an estimated probability greater than a defined minimum. For other situations, only qualitative limits will be feasible, e.g., events which, although of low probability, can be reasonably forecast based on credible scientific considerations.

15. Guy Gunningham, III, Executive Legal Director, Nuclear Regulatory Commission.

(1) In our opinion, the limiting conditions contained in the current regulation provide a reasonable description of the circumstances in which an agency should engage in forecasting. Thus, forecasting should only be undertaken when the gap in information or area of scientific uncertainty has been shown to bear some relevance to significant adverse impacts that are important to the decision or that must be considered if a reasoned choice is to be made among alternatives. Uncertainties respecting inconsequential environmental effects do not need to be considered. The extent to which an agency should develop a forecast is best determined by the rule of reason, as applied to the circumstances of that case. The forecast should identify the full range of responsible opinion on environmental effects. It should also have some basis in reality; for example, there should be some evidence that a) the events postulated in the forecast are meaningfully related to the proposed action; b) there is a real possibility, although not necessarily an immediate likelihood, that these events will occur; and c) there is an information base which indicates the likely consequences of these events.

(2) One way to structure such an analysis is to perform a probalistic risk assessment (PRA). Risk is the probability of the undesirable event times the severity or magnitude of the consequences. NRC uses PRA to evaluate both the probability of occurrence of severe (Class 9) accidents and the environmental consequences that may be caused by those events.

PRA provides information which answers the questions: what can go wrong? how likely is it to occur? what will be the outcome?

(3) At the present time, it is not clear to what extent agencies may be required, by reason of CEQ's worst case analysis regulation, to evaluate certain types of low probability/severe consequence events which under the rule of reason would not otherwise require consideration because the likelihood that those events might occur is so remote as to render them insignificant. The NRC staff believes that the regulation should not be construed to broaden the scope of NEPA; instead, it should be applied and interpreted in a manner that is consistent with the judicial rule of reason that states that agencies need not discuss in details events whose probabilities they believe to be inconsequently small.

(4) It would be extremely difficult to establish thresholds which could be meaningfully applied to all circumstances; threshold standards, whether of severe consequences, probability, or scientific credibility are meaningnful only to the extent that they are event or disipline specific.

In our view, the NEPA process could benefit if the CEQ regulations recognized, by making the use of threshold standards matter of agency discretion, that not every postulated scenario must be considered. For example, scenarios which are not supported by credible scientific evidence could be excluded from consideration or a peer review process could be used to establish probablistic limits for certain thresholds. Thresholds standards should neither mandated nor excluded by CEQ regulations.

(5) The NRC looks at a spectrum of scenarios, including "worst case", but uses to best estimates to present the environmental consequences weighted by the frequency of various conditions that may pertain during the scenarios. To interpret the "worst case" as a command to describe only the most disasterous scenario is to render the concept useless to a decisionmaker. Generally, the term "worst case analysis" refers to the analysis of a spectrum of possible events, including both those with severe consequences and a very low probability of occurrence and those with less severe environmental consequences and a higher probability of occurrence.

Attachment: NRC Statement of Interim Policy on Nuclear Power Plant Accident Considerations under NEPA (implementation of worst case analysis provision, June 13, 1980).

16. William Vaughan, Acting Assistant Secretary for Policy, Safety and the Environment, Department of Energy.

(1) Forecasting is inherent in the EIS process. The degree to which agencies must engage in speculation when confronted with scientific uncertainty or gaps in information depends upon the circumstances and the issues. In an analysis of accident risk, using probabilistic methods, it is reasonable and necessary to engage in a certain degree of speculation as to potential events and outcomes so that a reasonable spectrum of probabilities and consequences can be presented to the decisionmaker.

In some cases, speculation should not be required. For example, if there is significant scientific uncertainty, it is of little value to speculate without basis as to which value of a range of scientifically based effects is more or less likely to represent reality. In such cases, the agency should present a range of effects based on its assessment of available credible scientific analyses. The Department does not, however, see any NEPA provision that would require the agency to perform its own independent research to fully resolve these questions of scientific uncertainty.

(2) If the problem is amenable to quantitative statistical methods, then the analysis should present a reasonable range of potential outcomes ranging from relatively high probability to low probability situations. Such analysis should be limited by reasonably conservative assumptions made by the agency, but should not extend to very remote and speculative circumstances.

Where issues of genuine scientific uncertainty are considered, the Department believes that there is a responsibility under NEPA to present a range of possible effects based on the agency's assessment of available, credible scientific analyses and information. However, the agency should have the discretion to determine when significant scientific uncertainty exists - i.e., supported by technical information, a reasonable degree of analysis and peer review. The analysis should remain neutral: i.e., no best or worst case, just a range of results.

(3) To the extent that the regulation is being interpreted as requiring

analyses of outcomes so remote and speculative in nature or without scientific foundation that they are probably discounted in the decision-making process, then it goes beyond the rule of reason.

(4) General, but not specific, thresholds are appropriate. DOE believes there are two general thresholds involved: a) the information must be important to the decision, and b) the means to obtain the information either does not exists or is excessively costly. A threshold of severe consequences could preclude an analysis with serious, although not severe consequences; a threshold of probability could preclude an analysis of low probability but severe consequences. A specific threshold of scientific credibility may have some merit, but would be difficult to define and apply.

(5) The term "worst case" is not appropriate for this type of analysis. In situations involving scientific uncertainty, the range of analysis should be determined by the available scientific evidence and not by what is "worst.' In situations using probalistic analysis, worst case is inappropriate because it focuses attention on the most extreme consequences which are often of little use to decisionmaking and neglects the analysis of more meaningful possibilities. Further, in the context of a regulation, the term does not convey the clear meaning necessary to establish compliance. As a practical matter, any worst case analysis is potentially subject to challenge as deficient since someone could always conceive of a case worse than the "worst case" analyzed by the agency.

If the term were retained, it should be defined as the case the agency selects as representing the situation where maximum credible consequences or risks would occur.

Other comments: A clarifying change to the regulation to embody a "reasonably conserative" limit on probability/consequence analyses appears appropriate in dealing with statistical analysis. When dealing with the presentation of scientific-based information, the rule of reason should be applied to bound the discussion by limiting it to what is "credible scientific analyses".

From a technical point of view, two general technical/analytical presentations are often employed to address the problem of uncertainty: 1) information based on establised stochastic and other forecasting methods, including quantiative analysis of probability, consequences and risk; and 2) information based on established, credible scientific methods, including hypothesis, experimentation, analyses and verification. DOE believes that the CEQ approach to this regulation should encourage the use of the above two methods (discussed much more fully in the letter) and establish general regulatory guidance on limiting the scope of the analysis. It should leave the particulars of which approach to pursue, and how to pursue it, to the discretion of the agencies.

17. Joseph Canny, Acting Director, Office of Transportation Regulatory Affairs, Office of the Secretary, U.S. Department of Transportation.

(1) We recommend that the regulation recognize the distinction between actions where typical environmental effects are known and can be measured, and actions where the risk of accident is the only factor which has potential to significantly affect the environment. We also recommend that agencies not be required to examine consequences that are less than reasonably forseeable.

(3) To make a reasoned choice of alternatives, the decisionmakers must consider the overall risks. The analysis must allow a balancing of the worst case, having low probability, with the risks associated with accidents having lower consequences but higher probability.

(4) We suggest that a standard of reasonable forseeability be used as a threshold for requiring a worst case analysis.

Attachment: comments from Department of Transportation's Research and Special Programs Administrations, based upon their experience with the regulation in the promulgation of regulations for the long-range transport of highly hazardous material on the highways and their successful defense of that analysis in City of New York vs. Dept. of Transportation.

18. John Wesler, Director of Environment and Energy, Federal Aviation Administration.

When we need to do a worst case analysis, it is usually for aircraft noise and we usually employ forecasts. Rather than basing such analysis on pure speculation, we generally base the analysis on what the regional office realistically anticipates for use of the airport, plus a "little more growth" than what is realistically anticipated.

Setting a threshold standard to trigger the requirement would be very difficult.

It is our view that the concept of a "worst case analysis" should be changed to one of a "most practical case analysis".

19. Carl Schafer, Jr., Director, Environmental Policy, Office of the Assistant Secretary of Defense for Manpower, Installations and Logistics, Department of Defense.

(1) We recommend deletion of subparagraphs (a) and (b) in the regulation, leaving only the first sentence of the regulation requiring full disclosure of information gaps and uncertainty. An agency should not have to engage in outright speculation in predicting impacts. The enumeration and specificity of the potential impacts should be detailed enough to adequately describe the reasonably anticipated results, but they need not be so exhaustive as to blur the truly significant and likely impacts. Speculation about horrors (the common interpretation of the term worst case analysis) misleads the public without aiding the decisionmaker.

The extent to which an agency engages in forecasting should be keyed to the presentation of meaningful information in the fact of uncertainty. Uncertainty may involve either the magnitude of an impact or the probability of its happening.

(2) One cannot forecast that which is, by definition, unknown or uncertain. An EIS should instead describe the uncertainty, its significance, and responsible scientific disagreements about it. Where reasonable forecasting is possible, no special rule is required. Speculation has no place in an EIS. In some cases, a probability analysis would be useful; in other instances, a quantiative statistical method could be used. Analyses should discuss reasonably forseeable effects and the probability of their occurrence based on professional judgment and experience in a way that decisionmakers and the public can understand.

(3) The regulation repeals the rule of reason. In view of the trend in judicial interpretation, regulatory guidance should emphasize the rule of reason. Since the very concept of worst case analysis is undefined, the term may not lend itself to a rule of reason approach. Without clear definition, an agency will always be hard pressed to defend its analyses no matter how sincere its efforts.

(4) It is is doubtful that any threshold could be established which would alleviate the problem and be appropriate for all circumstances. The decision on when and how to prepare a worst case analysis should be based on what is reasonable and significant in the light of scientific and technical knowledge. EIS(s) could contain more than one worst case; the agency's and one based on responsible opposing opinion. However, minority opinion having little basis in fact or credible scientific standing should not trigger the requirement.

(5) The term "worst case" does not appear to be appropriate if a choice among options is made based on disclosure of credible scientific opinion and not incredible worst case speculations. The term connotes doomsday predictions, and thus tends to cause agency resistance to the process. A less inflammatory phrase such as "environmental risk analysis" or "maximum credible event" may be better. However, the term "worst case" has become accepted language and a change now may tend to confuse the issue further.

20. Robert Dawson, Acting Assistant Secretary of the Army for Civil Works, Department of the Army.

(1) A federal agency should enage in reasonable speculation or forecasting when there is a lack of important information about a direct or an indirect effect of a proposed action for which the agency is preparing an EIS. Existing CEQ regulations define the direct and indirect effects agencies must consider as the reasonably forseeable results of a proposed action. If an agency lacks important information about such effects, the agency should engage in reasonable and useful forecasting or speculation about the likely consequences of proceeding without the information.

(2) The agency should not ignore existing credibe data, imagine or create its own information, or conjure the unforeseeable. Rather, the agency should to the extent possible, consider potential consequences with a basis in credible scientific evidence. The EIS should carefullly circumscribe and disclose the areas for which there is a lack of important information.

(3) The regulation repeals the rule of reason. The current wording of the regulation suugests an agency must enter the realm of the unknown and fantasize the worst result imaginable regardless of the credibility of such conjecture or of the probability or improbability of its occurrence.

Court decisions have made this trend clear. Unbridled conjecture will serve neither the environment nor the taxpayers.
(4) Establishing a threshold is unnecssary and would probably add another broad concept that would be meaningless until interpreted by the courts. An agency's decision should return to the customary rule of reason, made in the light of scientific and technical knowledge available at the time.
(5) The term "worst case" is inappropriate and misleading. It is theoretically impossible to define the worst case. More importantly, attempts to fantasize the worst case are not useful to the decision maker. The requirement also establishes an unattainable standard and diverts resources and public attention from appropriate inquiry. The regulatory label should reflect how decisionmakers should deal with a lack of important information about an effect of a proposed action.

21. Martin Rivers, Director, Environmental Quality, Tennessee Valley Authority.
(1) Federal agencies should engage in forecasting or speculation in the face of missing information and scientific uncertainty when such information is essential to a reasoned choice among alternatives or is important to understanding the potential adverse impacts of an action.
(2) We believe that it is important that the NEPA document clearly state at the outset that there is scientific uncertainty or missing information. The accompanying worst case analaysis should then be structured to present an indication of the proability or improbability of a range or distribution of possible impacts associated with the environmental parameter or effect in question. Some indication should be provided as to the confidence level associated with the forecast.
(3) The error in the regulation is not that the analysis required goes beyond the rule of reason but that the regulation fails to expressly state that the analysis should be bound by the rule of reason.
(4) Establishing threshold standards is the key to making the regulation a meaningful component of the NEPA process. The suggested standard of severe consequences would have little utility, because the possibility of severe consequnces would be present in most situations involving an EIS. The probability threshold suggestion has three problems: first, any level chosen would involve some degree of arbitrariness; second, if the forecasted consequences are severe enough, the agency and the public should probably be alerted to the possibility, however low, that the event could occur; and three, a great deal of agency resources would have to go into making a realistic probability determination.

Of the three thresholds suggested, the "scientific credibility" suggestions provides the best means of providing boundaries for worst case analyses. The possibility of an event occurring should be scientifically credible before an agency is required to give it serious consideration in a worst case analysis. For example, because of the size of a reservoir, it may not be scientifically credible to assume that an entire species of fish can be entrained and that it is physically possible that the entire population of a bottom feeding species could eventually migrate to the immediate vicinity of the intake structure. This situation would not be sufficient to require consideration of the possible loss of the entire species unless there was some credible scientific basis for assuming that such a migration would occur.
(5) We believe the term "worst case" should continue to be used, as it has gained a general understanding and is widely used. It should be defined as an analysis which presents a spectrum of reasonably forseeable impacts for which there is credible scientific support including that event which presents the potentially worst impact.

22. Daniel Oliver, General Counsel, U.S. Department of Agriculture.
(1) An agency should identify information which is missing due to scientific uncertainty or lack of data and which concerns significant adverse effects on the human environment. Because forecasting is based upon actual information, an agency cannot forecast if information is unknown or unobtainable. An agency may speculate about missing information. The missing information must be relevant to the ultimate decision. Concerns about the missing information should be of generally accepted credibility in the scientific information before speculation is required. Credible scientific views opposite to those in the environmental analysis should be recognized.
(2) The analysis should be structured to include a reasonable range of possible adverse consequences related to the proposed action. It should be detailed enough to enable the decisionmaker to make a reasoned decision and to inform the public, but also be concise enough to fit within the EIS

page limitations and other guidelines established by the CEQ regulations. The analysis should be prepared in non-technical terms, to the extent possible. Examples of risk should be put in terms that the decisionmaker and the public can relate to from everyday experience.

(3) Yes, the regulation requires federal agencies to go beyond the rule of reason. In several specific provisions, the CEQ regulations embody a rule of reason standard (for example, in defining effects and in the requirement to analyze alternatives). Both courts and commentators have shown confusion about whether the rule of reason applies to Section 1502.22. The correct view is to require a measure of reasonable speculation only where a real possibility of the consequence has been shown. Thus, an agency is required to speculate only about those likely consequences that have a basis in credible scientific evidence.

(4) The thresholds suggested in our previous answers should be the basis for the analysis. We do not believe that additional threshold standards such as severe consequences should be applied, because of the wide variety of activities to which the requirement applies. The existing threshold that triggers speculative analysis is a recognition that the unobtainable missing information is relevant and essential to a reasoned choice among alternatives. When important information is missing, speculation about consequences of reasonably forseeable events should occur only where such consequences have a basis in credible scientific evidence, excluding consequences which are purely hypothetical or conjectural. An amendment to the regulation is required to make this clear.

(5) Although the term "worst case" may be appropriate if it is defined as a method for estimating or evaluating the risk of a low probability but reasonably forseeable event of high consequence, speculation on the ultimate "worst case" is not productive or informative to the public or decision-makers. The agency should only consider a reasonably forseeable event which, in its judgment, poses a realistic, if remote, probability of occurrence. The agency should have some flexibility regarding the depth and type of analysis. Various methods of considering potential impacts are available, but no single method will be appropriate in all situations or for all agencies.

23. Lawrence Jenson, Associate Solicitor, Energy and Resources, Office of the Solicitor,. U.S. Department of Interior.

(1) When an agency is faced with a situation where the full extent of an action's environmental effects are incalculable, and potential outcomes are truly uncertain, the agency should disclose the uncertainty and identify the risks of proceeding in the face of it. But an agency should not be asked to consider those risks from that uncertainty which are not important to a reasoned choice among the alternatives being considered. Conversely, when the risks associated with uncertainty surrounding the agency's decision are important to the decision to proceed, it is not only reasonable to expect, but incumbent upon the agency, to consider the uncertainty and its risks more fully.

There are instances where a base of information does not exist to allow an agency to discuss with any confidence the risks of proceeding with an action in the face of uncertainty about the full extent of its environmental effects. In these instances, all that can be expected of an agency is a candid acknowledgement that uncertainty exists and that the risks of proceeding with the action are indeterminate.

Where a base of information does exist allowing an agency to discuss with confidence the risks of proceeding in the face of uncertainty, the agency should do so and focus its efforts on those consequences that could occur.

An agency should not be expected to convert uncertainty into a fictional certainty, as the existing regulation requires. The crucial questions for an agency should be how to narrow the uncertainty and decide the proper course of action given the uncertainty and its risks.

(2) The question of how to structure an analysis of uncertain environmental effects is one which should be committed to agency discretion. The analysis structure will depend upon the nature of the uncertainty and the risks to which it gives rise. If the problem is amenable to quantitative statistical methods, then the analysis should present a range of potential outcomes, ranging from relatively high probability to low probability. Such analysis should extend to and be limited by reasonably conservative assumptions. If the problem cannot be addressed quantitatively, it should be described qualitatively as best the agency can do so.

If genuine issues are raised by divergent opinions, the agency should present and examine the full range of opinion on the subject. However, the agency should have discretion to determine on a sound basis when this divergent opinion is significant. If the agency has valid reasons for identifying one opinion as the more valid, it should do so; otherwise, the analysis should remain neutral.

(3) Yes, the regulation requires agencies to go beyond the rule of reason. [Extensive discussion of case law supporting the rule of reason in NEPA cses]. Just before the issuance of CEQ's regulation in 1978, including Section 1502.22, under NEPA case law, an agency could not avoid forecasting and describing significant and adverse environmental effects from its proposed action, simply because the inquiry required some degree of speculation. However, the speculation implicit in the inquiry was bound by the rule of reason. The agency did not have to resolve divergent opinions nor delay its actions until more information about the actions environmental efffects became known, nor discuss the possibility that effects other than those which were reasonably forseeable might occur.

Section 1502.22 added one additional requirement to the codification of this case law - the worst case requirement. "Worst case" was never defined, nor was the purpose of he regulation or its basis stated by CEQ. No prior NEPA case law ever used the term "worst case" in the context of uncertainty.

CEQ's guidance in the "Forty Most Asked Questions Concerning CEQ's NEPA Regulations" added to the problem by stating that , "NEPA requires that impact statements, at a minimum, contain information to alert the public and Congress to all known possible environmental consequences of agency action."

Both the regulation itself and this interpretation violate the urle of reason. The regulation requires an agency to consider all possible consequences of an action regardless of how remote or speculative, simply because there is uncertainty. The regulation trivializes NEPA, is based on an erroneous legal proposition, strains credibility, and is untenable. In theory, there is no end to the inquiry required. Recent Ninth Circuit case law demonstrates the worst case analysis regulations's lack of rationality.

(4) An agency's first duty is to seek out information about an agency's environmental effects; there are times, however, when obtaining more data may prove impractical in terms of time and/or money, or be beyond he state of the art. In these instances, before an agency acts, it should disclose the uncertainty and explain why the methods or costs of obtaining more data to resolve that uncertainty are unreasonable.

Beyond asking the question: does the uncertainty pose risks that are important to deciding whether to proceed with the action, and, if yes, accounting for that uncertainty, thresholds should not be established. They would only add confusion.

(5) The term "worst case" is inappropriate for describing an agency's disclosure and consideration of uncertainty surrounding an action's environmental effects. The words imply that the uncertainty can be converted into a fictional certainty, which quite often can result in wrong or misleading statements about the reality of the situation. Also, the term focuses attention to the most extreme consequences, and shifts the proper considerations from the more likely to the least likely consequences.

We do not believe another label should be chosen. Instead of the worst case analysis regulation, we urge CEQ to return to the rule reason as fashioned by the courts in the years preceding the regulation.

ENVIRONMENTAL MESSAGES

Question: On page 10 of your justification, you mentioned that, "...the agency is actively involved in both the preparation of and commenting on drafts of environmental messages, executive orders and decision memoranda."

In that regard, how many person hours were expended by CEQ in 1984 and 1985 to support the preparation of presidential environmental messages?

Please summarize and include a copy of your comment on Executive Orders 12498 and 12291.

Answer: A daily log of time expended by the Council on Environmental Quality and the Office of Environmental Quality personnel in the preparation of and commenting on "drafts of environmental messages, Executive Orders and decision memoranda" is not kept. However, it is estimated that a minimum of 1,000 person hours are spent annually by the agency for these activities.

For example, each of the Council's Annual Reports contains "The President's Message to The Congress of the United States." This message is drafted by the agency staff.

The Chairman of CEQ is a member of the Cabinet Council on Natural Resources and Environment. This Cabinet Council meets to discuss environmental concerns of the various departments and the Administration. The Cabinet Council also has a Secretariat with regular meetings, which are attended by one of the Members of CEQ.

The agency staff assists in drafting Presidential Messages on special occasions such as the President's Message in support of a moratorium on commercial whaling by the International Whaling Commission.

Although the President has not delivered an Environmental Message to Congress which dealt solely with environmental issues, his 1982, 1983, 1984, and 1985 State of the Union Addresses did discuss environmental concerns. In addition, the President has issued numerous statements about our Nation's environmental concerns and his programs and policies for solving environmental problems. Examples include statements delivered on the occasions of Earth Day, the Bicentennial Year of the American Bald Eagle, National Geographic Dedication Ceremony, National Campers and Hikers Campvention, Camp David Radio Addresses, International Union for Conservation of Nature and Natural Resources meeting, and presentation of the Fourteenth CEQ Annual Report at Roosevelt Island.

You have referred to two Executive Orders: Executive Order 12291, "Federal Regulation" 3 CFR 127 (1982), Feb. 17, 1981 and Executive Order 12498, "Regulatory Planning Process", January 4, 1985. Both of these Executive Orders are regulatory in nature and do not deal specificially with environmental policy; therefore, CEQ was not requested to comment on them.

HOSTING OF FOREIGN ENVIRONMENTAL OFFICIALS

Question: In both 1985 and 1986, you include hosting Japanese and Russian environmental officials as major programs.

Why is this not done by the Department of State?

Is CEQ reimbursed by the Department of State for the costs incurred?

Answer: The National Environmental Policy Act (NEPA), in establishing the Council on Environmental Quality, charged the Council with overseeing the activities of the agencies of the Federal Government to determine whether the policies set forth in Title I of NEPA are being achieved. The agencies are required under Title I to "lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment." (42 U.S.C. 4332)

Further, Executive Order 11514, directs the Council to "Advise and assist the President and the agencies in achieving international cooperation for dealing with environmental problems, under the foreign policy guidance of the Secretary of State." (42 U.S.C. 4321, note)

Russian Exchange: Following execution of the 1972 Agreement Between the United States and the USSR on Cooperation in the Field of Environmental Protection, agreed to and signed by Presidents Nixon (U.S.) and Podgorgny (U.S.S.R.), representatives of both countries were appointed to implement the Agreement. On the U.S. side, the Chairman of the Council on Environmental Quality was appointed. There were several projects within the Agreement and the Council's General Counsel was appointed to Chair "Legal and Administrative Measures for Protection Environmental Quality." This appointment has remained throughout the life of the Agreement. The Russian exchanges which we have included in our budget submission are part of this Agreement.

Japanese Exchange: A simiiliar Agreement between the Governments of the United States and Japan was signed in August, 1975. This Agreement was to remain in force for five years, to be extended upon mutual agreement of both parties. It was extended for an additional five-year period in August, 1980. The Council on Environmental Quality is the U.S. Co-chairman of the Joint Environment Impact Assessment Project under this Agreement. The Japanese exchanges which we have included in our budget submissions are part of this Agreement.

The reason these exchanges are not directed by the Department of State is because the responsibility was assigned to the Council in each case. The Council has worked closely with the Department of State, and other relevant agencies in carrying out our responsibilities under these exchanges.

The Council is not reimbursed by the Department of State for costs incurred for either exchange.

STUDY FUNDING SOURCES

Question: In your agency accomplishments for 1984, you cite the publication of "Corporate Use of Information Regarding Natural Resources and Environmental Quality."

Why was this publication not paid for by the private sector or a private sector foundation?

Did you seek a foundation to support it?

Are there any similar activities in the fiscal year 1986 budget?

Answer: Over one fourth of the funding for this $275,000 project was derived from corporate and non-profit organization sources.

This study, directed by Russell Train, President of World Wildlife Fund - U.S., evolved out of the Cabinet Council Global Issues Working Group in its examination of various federal programs pertaining to natural resources and environmental quality data and forecasting. The final report contained several recommendations for improving the usefulness of government resource information and strengthening federal statistical policy management. These recommendations have been presented to federal agencies for consideration in improving their reporting capabilities and in reducing costs through information sharing and elimination of duplicative efforts.

At present, there are no plans for any similar activities in fiscal year 1986.

FEDERAL RISK ASSESSMENT PROGRAMS

Questions: In view of the fact that one of your basic objectives (p. 9) is to, "help coordinate federal environmental programs that involve more than one agency," how are you coordinating the Environmental Protection Agency's decision to make increased use of risk assessment with the National Science Foundation's decision to pull out of this area?

Answer: CEQ supports the concept of risk assessment and is a member of the recently established working group on risk assessment under the Cabinet Council on Natural Resources and the Environment. CEQ is working with the Office of Science and Technology Policy in developing a coordinated approach to look at the scientific basis of risk assessment activities across federal agencies.

The National Science Foundation has eliminated funds used for joint interagency projects, not funds used internally for risk assessment activities.

Question: On page 4 of your justification, you mention that $100,000 will be used to support the newly established Cabinet Council Working Group on Risk Assessment. The National Science Foundation, in its 1986 budget, has requested no funds for risk assessment.

If OMB permitted NSF to end funding for risk assessment, does this mean it is not an Administration priority?

Answer: It is important to note that agencies such as EPA and the Department of Health and Human Services are intensifying efforts in this area. CEQ'S support of the Cabinet Council Working Group on Risk Assessment involves the commitment of $100,000 for programs designed to better coordinate risk assessment activities across federal agencies.

The 14th annual Environmental Quality Report published by CEQ described risk management as "Probably the most important and most difficult government role emerging in the 1980s...." (Environmental Quality 1983, p. 11). The Report also contained 2 policy recommendations: "First, government agencies and laboratories engaged in risk assessment should attempt to make their procedures consistent.... Second, federal agencies with responsibility to manage risk should be given the regulatory flexibility to limit exposures to hazardous substances in the most cost-effective way" (Environmental Quality 1983, p. 12).

DETAILEES TO CEQ

Question: What detailees serve with CEQ/OEQ? How long have they been at CEQ/OEQ? From what agencies do they come?

Answer: This information is provided in the chart below.

DETAILEES TO CEQ*

PARENT AGENCY	RESPONSIBILITIES	MONTHS OF SERVICE	FISCAL YEAR(S)	REIMBURSABLE
Army Corps of Engineers	Global Issues	8	1984	No
Department of Agriculture	Secretary	22	1984-5	No
Department of Agriculture	Science Policy	2	1985	No
Department of Interior	Water Research Center & Information Clearinghouse Study	10	1984	No
Department of Interior	Environmental Monitoring and Data	12	1985	Yes
Environmental Protection Agency	Annual Report Global Issues	19	1984-5	No
Environmental Protection Agency	Annual Report Global Issues	6	1984	No
Government Printing Office	Annual Report -- Printing, Binding & Distribution Public Affairs	11	1984-5	No

*As of March 29, 1985.

SUBCOMMITTEE RECESS

Senator DOMENICI. The subcommittee will stand in recess until tomorrow at 10 o'clock in this room, S-124, when we will hear from the National Science Foundation and the Veterans Administration. We stand in recess until that time.

[Whereupon, at 11:36 a.m. Wednesday, March 27, the subcommittee was recessed to convene at 10 a.m. Thursday, March 28.]

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT-INDEPENDENT AGENCIES APPROPRIATIONS FOR FISCAL YEAR 1986

THURSDAY, MARCH 28, 1985

U.S. SENATE,
SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10 a.m. in room SD–124, Dirksen Senate Office Building, Hon. Jake Garn (chairman) presiding.

Present: Senators Garn, Abdnor, Proxmire, Domenici, and Lautenberg.

NATIONAL SCIENCE FOUNDATION

STATEMENT OF ERICH BLOCH, DIRECTOR

BUDGET REQUEST

Senator GARN. The subcommittee will come to order.

The National Science Foundation is the principal Federal agency for the support of basic research across all fields of science. NSF accounts for about 27 percent of all Federal support for research going to academic institutions. About 2,000 colleges, universities, industrial firms, and other organizations participate in NSF programs through over 13,000 grant awards.

For fiscal year 1986, you are requesting $1.6 billion. This represents an increase of $98.2 million, which is the net effect of: an increase of $96.8 million in research and related activities; an increase of $9.2 million in the Antarctic Program; a decrease of $5 million in science and engineering education; and a decrease of $1.8 million in your Special Foreign Currency Program.

I am pleased to welcome you here for your first appearance before this subcommittee. Please proceed with a summary of your opening statement.

Mr. BLOCH. Thank you, Mr. Chairman.

It is indeed a pleasure to be here this morning to talk about the NSF. I have a written statement, but I will only highlight the main points.

PREPARED STATEMENTS

I also want to extend the apologies on behalf of Dr. Roland Schmitt, the Chairman of the National Science Board, who could not be here today. He also has a statement which I will submit for the record.

Senator Garn. We will be happy to place it in the record.

Mr. Bloch. Thank you.

[The statements follow:]

STATEMENT OF ERICH BLOCH, DIRECTOR, NATIONAL SCIENCE FOUNDATION

MR. CHAIRMAN AND MEMBERS OF THE SUBCOMMITTEE:

IT IS A PLEASURE TO BE HERE THIS MORNING TO TALK ABOUT THE NATIONAL SCIENCE FOUNDATION.

MY FIRST SIX MONTHS AS DIRECTOR OF THE FOUNDATION HAVE BEEN EXCITING, AND I LOOK FORWARD TO DISCUSSING WITH YOU OUR PROPOSED PROGRAMS FOR 1986 IN CONSIDERABLE DETAIL.

IN MY DISCUSSION TODAY I WILL FOCUS ON:

- THE CHALLENGES FACING THE SCIENTIFIC COMMUNITY, AND THE IMPLICATIONS THESE HAVE FOR THE SOCIAL AND ECONOMIC FABRIC OF THE U.S.
- THE FEDERAL ROLE, AND IN PARTICULAR, THE RESPONSIBILITIES OF THE NATIONAL SCIENCE FOUNDATION FOR SCIENTIFIC AND ENGINEERING RESEARCH.
- THE STRATEGY THE FOUNDATION PURSUES TO MEET THESE RESPONSIBILITIES, AND CARRY OUT THIS ADMINISTRATION'S STRONG POLICY FOR BASIC RESEARCH.

LASTLY, I WILL HIGHLIGHT THE PROPOSED BUDGET FOR 1986, AND DISCUSS SEVERAL ACTIVITIES IN GREATER DETAIL.

FIRST, I WOULD LIKE TO EXTEND MY APOLOGIES ON BEHALF OF DR. ROLAND SCHMITT, CHAIRMAN OF THE NATIONAL SCIENCE BOARD AND VICE PRESIDENT OF CORPORATE RESEARCH AND DEVELOPMENT FOR THE GENERAL ELECTRIC COMPANY, WHO COULD NOT BE HERE TODAY. HE ASKS THAT HIS STATEMENT BE SUBMITTED FOR THE RECORD.

DR. SCHMITT

1. ISSUES IN SCIENCE AND ENGINEERING

I AM THE FIRST NSF DIRECTOR FROM INDUSTRY. DURING MY CAREER IN INDUSTRY I LEARNED THE IMPORTANCE OF BASIC SCIENCE AND ENGINEERING RESEARCH FOR SUCCESS IN THE MARKETPLACE. SUCH RESEARCH IS ESSENTIAL FOR MAINTAINING OUR INDUSTRIES AT THE LEADING EDGE OF TECHNOLOGY, AND FOR THE CONTINUED ECONOMIC HEALTH AND THE NATIONAL SECURITY OF THIS NATION.

THE DEPENDENCY OF U.S. INDUSTRY ON BASIC RESEARCH IS INCREASING FOR SEVERAL REASONS:

- o TO STAY AHEAD OF INTERNATIONAL COMPETITION.
- o TO HAVE ACCESS TO NEW MATERIALS, PROCESSES, AND EQUIPMENT, AND THE PEOPLE ABLE TO APPLY THESE NEW TECHNOLOGIES.
- o TO KEEP UP WITH THE COMPLEXITY AND RAPID ADVANCES IN NEWLY EMERGING TECHNOLOGIES.

AT THE SAME TIME, THERE ARE PROFOUND ISSUES FACING THE SCIENCE AND ENGINEERING COMMUNITY.

THE LEAD OF U.S. SCIENCE AND ENGINEERING OVER THAT OF OTHER NATIONS IS NARROWING

THERE IS AN INCREASED REALIZATION BY INDUSTRIALIZED NATIONS THAT SCIENCE AND TECHNOLOGY ARE AT THE HEART OF ECONOMIC PROGRESS. AS A RESULT, WE ARE BEGINNING TO SEE RESEARCH EFFORTS EMPHASIZED BY FOREIGN TRADING PARTNERS, CHALLENGING THE U.S. LEADERSHIP ROLE IN EMERGING FIELDS SUCH AS SUPERCOMPUTERS AND BIOTECHNOLOGY.

EMERGING NATIONS ARE EMULATING THE SUCCESS OF INDUSTRIALIZED NATIONS BY CONVERTING RESEARCH RESULTS INTO MARKETABLE TECHNOLOGY.

WE MUST CONTINUE TO BE COMPETITIVE BY KEEPING OUR RESEARCH AND TECHNOLOGY ON THE CUTTING EDGE, AND BY BEING FIRST IN TRANSLATING RESEARCH RESULTS INTO PRODUCTS IN THE MARKETPLACE.

SCIENCE AND ENGINEERING ITSELF IS IN TRANSITION

THE RATE OF NEW DISCOVERIES AND DEVELOPMENT IN SCIENCE AND ENGINEERING IS INCREASING BY EVERY MEASURE WE HAVE. SO IS THE COMPLEXITY OF THE SCIENTIFIC ENDEAVOR, ITS TOOLS AND METHODS, DEMANDING MORE SOPHISTICATION AND HIGHER SKILLS BY THOSE IN THE FOREFRONT OF RESEARCH.

IN EMERGING NEW TECHNOLOGIES, SUCH AS BIOTECHNOLOGY AND COMPUTERS, RESEARCH IS ALSO BECOMING INCREASINGLY MULTIDISCIPLINARY, REQUIRING DIFFERENT APPROACHES AND NEW INSTITUTIONAL ARRANGEMENTS. FURTHERMORE, IT IS NOW POSSIBLE FOR SCIENTIFIC OBSERVATIONS TO BE MADE AND INTEGRATED OVER GLOBAL SCALES.

A NATURAL CONSEQUENCE OF THIS CHANGE IS THAT THE TOTAL COST OF RESEARCH, ESPECIALLY INSTRUMENTATION AND SPECIAL FACILITIES, IS INCREASING FASTER THAN IN PRIOR YEARS.

THERE ARE SHORTAGES IN THE SCIENCE AND ENGINEERING COMMUNITY

WE NEED TO BE CONCERNED ABOUT THE DECLINE IN THE PROPORTION OF U.S. CITIZENS PURSUING GRADUATE STUDIES IN SCIENCE AND ENGINEERING, AND THE SHORTAGE OF FACULTY IN CERTAIN AREAS OF SCIENCE AND ENGINEERING IN U.S. UNIVERSITIES.

THIS DECLINE LEADS NOT ONLY TO A POSSIBLE REDUCTION IN THE QUALITY OF INSTRUCTION AND RESEARCH, BUT ULTIMATELY, TO A POSSIBLE SHORTAGE OF PROFESSIONAL SKILLS REQUIRED BY INDUSTRY, GOVERNMENT, AND ACADEMIA.

EQUALLY IMPORTANT IS THE NEED TO UPGRADE AND MODERNIZE THE ACADEMIC RESEARCH ENVIRONMENT. MUCH OF THE EQUIPMENT AND INSTRUMENTATION IN UNIVERSITY RESEARCH LABORATORIES IS NO LONGER THE BEST AVAILABLE. LABORATORY SPACE SHOULD BE ABLE TO ACCOMMODATE THE USE OF MORE COMPLEX PROCESSES AND EQUIPMENT OFTEN DEMANDED BY NEW AND EMERGING RESEARCH.

SCIENTIFIC RESEARCH REQUIRES LONG TERM CONTINUITY

WHILE THERE IS INCREASING RECOGNITION OF THE IMPORTANCE OF SCIENTIFIC ENDEAVORS, THE NEED FOR LONG-TERM STABILITY IS UNDERESTIMATED AND NOT EVERYONE REALIZES THE LONG INCUBATION PERIOD REQUIRED FOR SCIENCE AND ENGINEERING ENDEAVORS. OVER THE LAST SEVERAL YEARS WE HAVE MADE VISIBLE THE COMMITMENT NECESSARY TO PRODUCE THE BEST RESEARCH AND GENERATE EXCEPTIONAL TALENT, AND WE WILL CONTINUE TO DO SO IN 1986.

2. NSF'S RESPONSIBILITY

THE NATIONAL SCIENCE FOUNDATION PURSUES ITS RESPONSIBILITY FOR THE HEALTH OF THE GENERAL SCIENTIFIC ENTERPRISE BY SUPPORTING THE MOST PROMISING FUNDAMENTAL, LONG-TERM RESEARCH BY THE BEST MINDS IN ALL FIELDS OF SCIENCE AND ENGINEERING.

THE PRINCIPAL PRODUCTS ARE TWOFOLD:

- NEW KNOWLEDGE AND DISCOVERIES AT THE CUTTING EDGE OF RESEARCH, AND

- THE EDUCATION AND TRAINING OF THE WORLD'S MOST TALENTED AND CREATIVE SCIENTISTS AND ENGINEERS.

GAINING A NEW AND DEEPER UNDERSTANDING OF NATURE AND REPLENISHING OUR SUPPLY OF SCIENTISTS AND ENGINEERS ARE ESSENTIAL IF WE ARE TO IMPROVE THE NATION'S INDUSTRIAL COMPETITIVENESS, DEFENSE, ECONOMY, AND HEALTH AND GENERAL WELL-BEING OF OUR CITIZENS.

OUR SUCCESS WILL DEPEND ON HOW WELL WE EDUCATE THE SCIENTISTS AND ENGINEERS OF TOMORROW AND HOW WELL WE PROVIDE FOR THE PURSUIT OF NEW KNOWLEDGE AND RESEARCH.

OUT OF A TOTAL OF NEARLY $8 BILLION OF BASIC RESEARCH FUNDED BY THE FEDERAL GOVERNMENT, THE NSF BUDGET REPRESENTS ONLY 17%. WHILE THE PERCENTAGE MAY SEEM SMALL, OUR RESEARCH ROLE IS VERY IMPORTANT AND UNIQUE. WE ARE CONCERNED PRIMARILY WITH STRENGTHENING SCIENTIFIC RESEARCH POTENTIAL AND SCIENCE EDUCATION PROGRAMS, AND NOT WITH SERVING AN END PRODUCT MISSION LIKE MOST OTHER AGENCIES ENGAGED IN RESEARCH SUPPORT. IN FACT, THE FOUNDATION PROVIDES 27 PERCENT OF ALL RESEARCH SUPPORT IN COLLEGES AND UNIVERSITIES.

3. NSF GOALS AND STRATEGIES

LET ME NOW TURN TO NSF GOALS AND STRATEGIES:

THE FIRST GOAL IS EXCELLENCE. IT HAS ALWAYS BEEN THAT WAY AND IT MUST CONTINUE. IN SCIENCE AND ENGINEERING RESEARCH, AS IN ANY CREATIVE ENDEAVOR, THE BEST IS VASTLY MORE VALUABLE THAN THE MERELY GOOD.

EXTERNALLY, IN OUR GRANTS AND CONTRACTS ACTIVITIES, EXCELLENCE MEANS MERIT-BASED PEER REVIEW. IT IS STILL THE BEST WAY TO ENSURE HIGH QUALITY AND THE BEST RETURN FOR THE NATION'S INVESTMENT.

INTERNALLY TO THE FOUNDATION, WE WILL CONCENTRATE ON EFFECTIVE AND EFFICIENT MANAGEMENT USING AUTOMATION WHERE POSSIBLE TO INCREASE OUR PRODUCTIVITY.

THE SECOND GOAL IS FOR NSF TO BE A CATALYST FOR CHANGE IN THE SCIENCE AND ENGINEERING COMMUNITY. THIS MEANS NOT ONLY PURSUING NEW RESEARCH OPPORTUNITIES, BUT ENCOURAGING NEW WAYS TO CARRY OUT RESEARCH.

- APPLYING INTERDISCIPLINARY APPROACHES TO NEW AND EMERG-

ING RESEARCH POSSIBILITIES.

- O DEVELOPING NEW RELATIONSHIPS BETWEEN GOVERNMENT AND PRIVATE INSTITUTIONS, AND BETWEEN INDUSTRY AND UNIVERSITIES.

- O INCREASING COMMUNICATION AMONG RESEARCHERS IN ALL RESEARCH DISCIPLINES, AND STIMULATING THE SHARING OF EXPENSIVE EQUIPMENT, FACILITIES, AND KNOWLEDGE.

WHILE WE MAY ENCOURAGE SCIENCE AND ENGINEERING RESEARCH TO MOVE IN NEW DIRECTIONS IN A CONCERTED WAY, WE MUST AND WILL CONTINUE TO SUPPORT INDIVIDUAL RESEARCH PROJECTS CARRIED OUT BY A PRINCIPAL INVESTIGATOR SCIENTIST AND A FEW STUDENTS. IT HAS PROVEN TO BE A SIMPLE YET MOST EFFECTIVE STRATEGY.

THE KEY IS TO BALANCE THIS WITH LARGE-SCALE COOPERATIVE EFFORTS. THERE IS AMPLE OPPORTUNITY AND NEED FOR BOTH; IT IS NOT ONE APPROACH OR THE OTHER.

THIRD, NSF MUST TRY TO IMPROVE THE HEALTH OF THE SCIENCE AND ENGINEERING INFRASTRUCTURE. INSTRUMENTATION, SPECIFIC FACILITIES INTEGRAL TO RESEARCH AND HUMAN RESOURCES SHOULD BE THE BEST TO REVITALIZE THE ACADEMIC RESEARCH BASE. WE WILL CONTINUE TO SUPPORT NEW AND ENHANCED INSTRUMENTATION AND ACCESS TO IT.

FOURTH, WE MUST CONTINUE TO HELP ATTRACT, EDUCATE, AND TRAIN STUDENTS FOR SCIENCE AND ENGINEERING. WE ARE DOING THIS THROUGH:

- O FELLOWSHIPS OPEN TO ALL QUALIFIED APPLICANTS;

- O SPECIAL PROGRAMS DIRECTED AT MINORITIES, WOMEN, AND THE HANDICAPPED;

- O PROGRAMS DESIGNED TO ATTRACT AND RETAIN FACULTY IN DISCIPLINES WHERE FACULTY SHORTAGES IMPEDE BASIC RESEARCH PROGRESS;

- O PROGRAMS KEYED TO THE IMPROVEMENT OF PRECOLLEGE SCIENCE AND MATHEMATICS EDUCATION; AND

- O INCREASED SUPPORT OF GRADUATE STUDENTS ON RESEARCH GRANTS.

Finally, we will continue to leverage government funds with private sector, state and local government, and academic support in all areas where cooperation is a possibility and in the best interests of all participants.

In order to move toward these goals and given the budget environment for FY 1986, the Foundation made decisions to maximize the funding available for academic science and engineering research activities. These include:

- Recognizing the need and the Administration's resolve to reduce administrative costs, we are holding down NSF's administrative costs, which are already low compared to those of similar organizations.
- Curtailing programs that are not in the mainstream of scientific and engineering research.
- Stretching out construction and acquisition of several major research projects.
- Making trade-offs with ongoing base programs in order to provide for enhancements in several key areas where research is essential to the Nation's pursuit of scientific and technological excellence and to training the next generation of scientists and engineers.

4. NSF Budget Request

Commensurate with the President's resolve to reduce the deficit, the FY 1986 budget request is tight and the increase minimal, but it continues the momentum established by this Administration, and supported by Congress, to keep U.S. science and engineering research the best in the world.

The Foundation's FY 1986 Budget Request totals $1,569.4 million or 4.4% above the FY 1985 Current Plan of $1,502.7 million. With the proposed deferral of $31.5 million in science and engineering education, total resources available to the Foundation in 1986 will be $1,601 million, or 6.5 percent more than 1985. It includes:

- $1,397.8 million for Research and Related Activities, an increase of $95.8 million or 7.4%.

- $120.1 million for the U.S. Antarctic Program, up 8.4%.
- $50.5 million of new obligational authority for Science and Engineering Education which combined with a proposed deferral of $31.5 million from FY 1985 provides total resources of $82.0 million, the same level as 1985.

This budget request, if approved by Congress:

- Maintains support at current levels for research of proven quality across all disciplines.
- Increases support for research related to U.S. economic competitiveness such as engineering research centers, and biotechnology.
- Increases programs that provide essential basic support for advances in science and technology, focusing in addition to the research, on instrumentation and specific facilities that are an integral part of the proposed research. Some facility activities, however, such as the construction of the Very Long Baseline Array will continue at a somewhat slower pace than originally planned.
- Focuses presidential young investigator awards on faculty younger than previous recipients and provides an additional $6.0 million to support 100 new awards in 1986 bringing the total to 500.

With this overview of our 1986 request let me turn to specific research activities and programs that are addressed in our budget request.

MATHEMATICAL AND PHYSICAL SCIENCES (MPS)

The FY 1986 Budget Request for MPS is $429.0 million, an increase of $32.4 million, or 8.2 percent, over the FY 1985 Current Plan. All divisions shared in the increase, with Computer Research, Physics and Chemistry up 7% each, Materials Research up 8%, and Mathematics up 15%.

The large increase in Mathematical Sciences is due to the fact that the Foundation is the major supporter -- more than 90% -- of

RESEARCH IN CORE MATHEMATICS, WHICH UNDERLIES MUCH OF THE WORK THAT IS UNDERTAKEN IN SCIENCE AND ENGINEERING.

OTHER HIGHLIGHTS INCLUDE CONTINUATION OF THE CORNELL ELECTRON STORAGE RING (CESR) UPGRADE BEGUN LAST YEAR; SUPPORT FOR ADVANCED MATERIALS RESEARCH; PARTICIPATION IN BIOTECHNOLOGY WITH OTHER DIRECTORATES; AND INCREASED SUPPORT FOR INSTRUMENTATION. IN FACT, THE MPS TOTAL FOR INSTRUMENTATION INCREASED 15.1 PERCENT, TO A TOTAL OF $102.1 MILLION.

ALL TYPES OF RESEARCH ACTIVITY BENEFITTED FROM THE OVERALL MPS INCREASE. SUPPORT FOR SCIENTIFIC RESEARCH PROJECTS IS UP 8.2 PERCENT TO $288.7 MILLION; SPECIAL EQUIPMENT PROGRAM INCREASES 9.3 PERCENT TO $21.2 MILLION; RESEARCH AT UNIVERSITY LABORATORIES CLIMBS 2.8 PERCENT TO $63.5 MILLION; AND SUPPORT FOR NATIONAL USERS FACILITIES INCREASES 9.2 PERCENT TO 55.6 MILLION. ALL OF THE ABOVE TOTALS INCLUDE SUPPORT FOR INSTRUMENTATION.

ENGINEERING (ENG)

WE ARE ALL CONCERNED ABOUT THE NEED TO MAINTAIN INDUSTRIAL COMPETITIVENESS, AND TO STRENGTHEN ENGINEERING RESEARCH AND EDUCATION IN THE UNITED STATES AT A TIME WHEN ENGINEERING IS UNDERGOING FUNDAMENTAL CHANGES.

TO DIRECTLY ADDRESS THIS CONCERN --MAINTAINING LEADERSHIP IN ENGINEERING OVER THE LONG TERM -- WE HAVE RESTRUCTURED THE ENGINEERING DIRECTORATE TO: ACHIEVE BETTER BALANCE BETWEEN MORE ESTABLISHED AND EMERGING DISCIPLINES OF ENGINEERING; GIVE SPECIAL EMPHASIS TO AREAS WITH UNIQUE OPPORTUNITIES AND NEEDS; AND STRENGTHEN LINKS BETWEEN ACADEMIC ENGINEERING AND INDUSTRY.

THE FY 1986 REQUEST FOR ENGINEERING IS $170.1 MILLION, AN INCREASE OF $20.0 MILLION, OR 13.3 PERCENT OVER THE FY 1985 CURRENT PLAN. WE HAVE PLACED EMPHASIS ON SUPPORT TO EMERGING FIELDS, UP 12.6 PERCENT TO $58.9 MILLION AND CROSS-DISCIPLINARY RESEARCH, WHICH INCLUDES THE ENGINEERING RESEARCH CENTERS (ERC'S), UP 57.6 PERCENT TO $31.5 MILLION.

THE ERC PROGRAM WAS INITIATED IN 1985 AT $10 MILLION, AND OUR FIRST AWARDS WILL BE MADE SHORTLY. FOR 1986 WE INTEND TO ADD $15 MILLION, BRINGING THE TOTAL UP TO $25 MILLION. MOST ERC'S WILL INVOLVE INTERDISCIPLINARY TEAMS OF SCIENTISTS AND ENGINEERS FROM INDUSTRY AND ACADEMIA. OUR GOAL IS TO ESTABLISH INNOVATIVE RESEARCH CENTERS THAT CAN MAKE REAL CONTRIBUTIONS TO MAINTAINING U.S. COMPETITIVE LEADERSHIP WHILE PROVIDING DIVERSE AND QUALITY

ENGINEERING EDUCATION.

IN ADDITION TO THE ERC'S, WE WILL BE FOCUSING ON NEW EMERGING FIELDS IN ENGINEERING SUCH AS ENGINEERING DESIGN, BIOTECHNOLOGY, COMPUTER-INTEGRATED ENGINEERING, AND LIGHTWAVE TECHNOLOGY. WE WILL, OF COURSE, CONTINUE SUPPORT IN THE TRADITIONAL ENGINEERING DISCIPLINES.

BIOLOGICAL, BEHAVIORAL, AND SOCIAL SCIENCES (BBS)

THE FY 1986 BUDGET REQUEST FOR BBS OF $272.1 MILLION IS AN INCREASE OF $20.1 MILLION, OR 8.0 PERCENT OVER THE FY 1985 CURRENT PLAN. ALL DIVISIONS WITHIN BBS HAVE INCREASES BETWEEN 5 AND 8 PERCENT OVER THE 1985 PLAN, WITH SOCIAL AND ECONOMIC SCIENCE UP 19 PERCENT.

THIS LARGE INCREASE IN SOCIAL AND ECONOMIC SCIENCE RELATES TO THE IMPORTANT - AND UNIQUE -- ROLE NSF HAS WITH RESPECT TO BASIC RESEARCH FOR CURRENT DATA BASE DEVELOPMENT, METHODOLOGICAL RESEARCH, AND FOR INSTRUMENTATION FOR THE ANALYSIS OF LARGE-SCALE DATA BASES. THIS RESEARCH IS USED EXTENSIVELY BY OTHER GOVERNMENT AGENCIES AND THE PRIVATE SECTOR.

THE MAIN FOCUS IN BBS, HOWEVER, WILL CONTINUE TO BE PROGRESS TOWARD INCREASING KNOWLEDGE ABOUT LIFE AND SOCIAL PROCESSES THROUGH RESEARCH ON BIOLOGICAL AND SOCIAL PHENOMENA. THE PRIMARY EMPHASIS WILL BE PLACED ON BIOLOGICAL SCIENCE RELATED TO BIOTECHNOLOGY, INCLUDING PLANT BIOLOGY RESEARCH ACTIVITIES AND POSTDOCTORAL FELLOWSHIPS IN THE PLANT SCIENCES; CHEMISTRY OF LIFE PROCESSES WORK IN MOLECULAR BIOLOGY IN COLLABORATION WITH CHEMISTRY: AND APPLICATIONS OF RECOMBINANT DNA TECHNIQUES TO PROVIDE LARGE QUANTITIES OF SUBSTANCES.

NSF IS THE PRIMARY FEDERAL SUPPORTER OF BASIC RESEARCH IN SYSTEMATICS AND ECOLOGY. SINCE THIS RESEARCH FORMS THE SCIENTIFIC BASE NECESSARY TO ASSESS THE POTENTIAL ENVIRONMENTAL IMPACT OF THE VARIOUS PRODUCTS AND BYPRODUCTS OF BIOTECHNOLOGY, IT WILL BE THE FOCUS OF SPECIAL ATTENTION THIS YEAR.

ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES (AAEO)

THE FY 1986 BUDGET REQUEST FOR AAEO IS $372.2 MILLION, AN INCREASE OF 5.8 PERCENT OVER THE FY 1985 CURRENT PLAN OF $351.7 MILLION. ALL DIVISIONS HAVE INCREASES IN 1986, WITH EARTH SCIENCES UP 12 PERCENT TO SUPPORT EFFORTS IN THE CONTINENTAL LITHOSPHERE

RESEARCH PROJECT, AND ARCTIC RESEARCH, UP 11 PERCENT TO IMPLEMENT THE NEW COORDINATING RESPONSIBILITIES UNDER THE ARCTIC RESEARCH AND POLICY ACT.

OTHER AREAS OF EMPHASIS INCLUDE CONTINUING THE UPGRADE OF NCAR COMPUTING CAPABILITIES AND CONSTRUCTION FOR THE VLBA, ALTHOUGH THESE MAJOR PROJECTS WILL CONTINUE AT A SLOWER RATE THAN PREVIOUSLY PLANNED. THE OCEAN DRILLING PROGRAM WILL BECOME FULLY OPERATIONAL AS SCHEDULED IN 1985, WITH CONSIDERABLE INTERNATIONAL PARTICIPATION IN PLANNING AND OPERATIONS.

U.S. ANTARCTIC PROGRAM (USAP)

THE 1986 REQUEST FOR USAP IS UP 8.3 PERCENT OVER THE 1985 PLAN, TO $120.1 MILLION. THE INCREASE INCLUDES UPGRADING TWO LC-130 AIRCRAFT, AS WELL AS EQUIPMENT AND FUNDS FOR RESEARCH PROJECTS. THIS FUNDING LEVEL ALLOWS THE UNITED STATES TO MAINTAIN AN EFFECTIVE PRESENCE IN THIS IMPORTANT AND STRATEGIC AREA, AND AT THE SAME TIME PROVIDES OPPORTUNITIES FOR SCIENTISTS TO CARRY OUT SIGNIFICANT RESEARCH IN THIS UNIQUE RESEARCH ENVIRONMENT.

ADVANCED SCIENTIFIC COMPUTER (ASC)

THE FY 1986 BUDGET REQUEST FOR ASC INCREASES BY $4.8 MILLION TO $46 MILLION. IN 1985, WE ARE PLANNING TO ESTABLISH THREE PERMANENT CENTERS WITH CLASS VII COMPUTERS, ONE BASED ON AN EXPERIMENTAL CONFIGURATION, AND ONE USING THE NASA SUPERCOMPUTER TRANSFERRED TO THE NSF IN LAST YEAR'S APPROPRIATION BILL.

SUPERCOMPUTER TIME WILL CONTINUE TO BE PURCHASED FROM THE TEMPORARY CENTERS SET UP DURING THIS TRANSITION PHASE. IN ADDITION, WE WILL IN 1986 PROVIDE SIGNIFICANT SUPPORT FOR LOCAL COMPUTING FACILITIES, NETWORK DEVELOPMENT, AND SOFTWARE SUPPORT.

THE NSF HAS A UNIQUE -- AND QUITE ESSENTIAL -- ROLE BECAUSE UNLIKE OTHER FEDERAL AGENCIES, IT DOES NOT IMPOSE MISSION CRITERIA IN SELECTION OF THE RESEARCH PROJECTS. MORE IMPORTANTLY, NSF CAN PROVIDE SUPPORT FOR COMPUTER RESEARCH AND COMPUTERS ACROSS A WIDE SPECTRUM OF DISCIPLINES. SUCH SUPPORT PROVIDES TALENT AND KNOWLEDGE THAT MIGHT NOT BE OTHERWISE AVAILABLE, ESPECIALLY IN THE TRAINING OF GRADUATE STUDENTS IN COMPUTER RESEARCH AND ENGINEERING.

SCIENTIFIC, TECHNOLOGICAL, AND INTERNATIONAL AFFAIRS (STIA)

STIA CARRIES OUT ESSENTIAL FOUNDATION RESPONSIBILITIES THAT cut across scientific disciplines or support certain initiatives. The FY 1986 Budget Request of $38.4 million is a net decrease of $6.1 million, or 13.8 percent less than the FY 1985 Current Plan of $44.5 million. It is the only major area with a decrease in 1986.

Funding responsibility for several programs has been transferred to the disciplinary activities to improve their effectiveness. This includes the Industry/University Cooperative Research Projects and Centers programs, Research Opportunities for Women, the Minority Research Initiation, and the Experimental Program to Stimulate Competitive Research Programs. These programs will now be funded in discipline-oriented research activities of the Foundation that were discussed earlier, and in many cases at levels HIGHER than the FY 1985 plan.

We will continue to fund programs and activities of the highest priority. Small Business Innovation Research (SBIR) increases $0.9 million to $13.3 million, and Science and Resources Studies (SRS) will continue maintaining and improving the existing science resources data base and performing periodic surveys.

However, some areas have been reduced, such as the 60% reduction in Policy Research and Analysis. The high priority work in this area will continue, e.g., science and technology questions raised by the NSB and Executive agencies.

Several other programs of lower priority -- Productivity Improvement Research, Ethics and Values in Science and Technology, and Intergovernmental Science and technology -- will be terminated. Researchers formerly supported through these programs will be able to compete for support in other NSF programs, for example in Social and Economic Science.

Finally, STIA International activities also decrease, although most support for international cooperative research projects and agreements will continue. The STIA international activities account for only about 10% of the Foundation's international efforts. In total, the Foundation's international activities will increase 5.1 percent to $150.2 million.

SCIENCE AND ENGINEERING EDUCATION (SEE)

The FY 1986 program total for SEE is 82.0 million. This total includes an FY 1986 Request for new obligational authority of $50.5

MILLION AND DEFERRAL OF $31.5 MILLION FROM FY 1985. WITH THE DEFERRAL, THE FY 1986 PROGRAM TOTAL REMAINS THE SAME AS THE FY 1985 LEVEL.

DEFERRAL

DESPITE OUR INITIAL OPTIMISM AND BEST EFFORTS THERE ARE SEVERAL FACTORS THAT MAKE IT UNLIKELY THAT WE WILL REACH OUR EARLIER GOAL OF FULL EXPENDITURE OF ALL SEE FUNDS (I.E., $113 MILLION) IN FY 1985, ESPECIALLY IN THE PRECOLLEGE PROGRAMS. WE WILL MEET OUR PREVIOUS GOALS IN THE GRADUATE FELLOWSHIPS AND COLLEGE SCIENCE INSTRUMENTATION PROGRAMS. HOWEVER, WE ARE ENCOUNTERING PROBLEMS IN THE PRECOLLEGE AREA.

THERE ARE SEVERAL REASONS FOR THIS. FIRST, FUNDING LEVELS IN THE PRECOLLEGE AREA HAVE OSCILLATED CONSIDERABLY OVER THE PAST DECADE. IN THE 1976 TO 1981 PERIOD, PRECOLLEGE FUNDING WAS ABOUT $20 MILLION PER YEAR; THEN IT DROPPED TO $3.4 MILLION IN FY 1982 AND $1.1 MILLION IN FY 1983; AND INCREASED TO ABOUT $68 MILLION IN AVAILABLE RESOURCES IN FY 1984.

NEITHER THE AFFECTED SCIENCE AND MATHEMATICS COMMUNITY NOR NSF WAS READY FOR SUCH AN INCREASE AFTER FY 1982 AND 1983. THE RESULT IN FY 1984 WAS THAT WE WERE ABLE TO SPEND $37.1 MILLION, BUT HAD TO CARRY OVER A $31.5 MILLION BALANCE INTO FY 1985. THIS CARRYOVER, PLUS THE ADDITIONAL $49.7 MILLION IN NEWLY APPROPRIATED FUNDS FOR PRECOLLEGE ACTIVITIES, GAVE US A TOTAL OF $82.0 MILLION TO OBLIGATE FOR THOSE ACTIVITIES IN FY 1985.

GEARING UP TO HANDLE INCREASES OF THIS MAGNITUDE TAKES TIME, ESPECIALLY IF WE ARE TO BUILD A COHERENT PROGRAM THAT ADDRESSES PRECOLLEGE SCIENCE AND MATH ISSUES WHILE MAINTAINING OUR STANDARD OF EXCELLENCE. THE PROGRAM ALSO NEEDS TO PROVIDE A BASE FOR FUTURE YEARS' ACTIVITIES.

OUR STAFF AND ORGANIZATION HAD TO BE COMPLETELY REBUILT, AND ONLY RECENTLY HAVE WE COME TO ADEQUATE EXPERTISE AND SKILL LEVELS. WE NOW HAVE TO BEGIN BUILDING A COMPREHENSIVE LONG RANGE PLAN TO DEAL WITH THE ISSUES RELATED TO SCIENCE EDUCATION AND TO MAKE SURE THAT THE RESEARCH EFFORTS THAT THE FOUNDATION SUPPORTS ARE COUPLED EFFECTIVELY TO THE OVER $144.5 BILLION INVESTMENT BEING MADE IN EDUCATION BY OTHER FEDERAL AGENCIES, AND BY STATE, LOCAL, AND PRIVATE SOURCES. CONGRESS SET ASIDE IN 1985 $2.0 MILLION FOR THIS PURPOSE, AND WE WILL GO OUT THIS SPRING WITH THE FIRST ROUND OF REQUESTS FOR PLANNING PROPOSALS.

IN SCIENCE EDUCATION, AS IN RESEARCH ENDEAVORS GENERALLY, CONTINUITY AND STABLITY ARE CRITICAL FOR EXCELLENCE. EVEN WHEN FUNDING IS AVAILABLE TO ATTRACT PROPOSALS, IT TAKES TIME FOR GOOD PARTNERSHIPS TO FORM AND BECOME PRODUCTIVE.

THE QUALITY OF PROPOSALS WE HAVE SEEN SO FAR IS MIXED. PART OF THIS IS DUE TO THE FACT THAT THE PROGRAM IS NEW, AND THE SPECIFIC ISSUES AND OBJECTIVES ARE JUST BEGINNING TO COME INTO FOCUS. WE HAVE SEEN AND FUNDED MANY EXCELLENT PROPOSALS. BUT IN SOME CASES EVEN A COLLECTION OF EXCELLENT PROPOSALS DOES NOT NECESSARILY MAKE A COHESIVE PROGRAM -- A PROGRAM THAT IS EFFECTIVELY COUPLED TO THE NATION'S SCHOOLS AND TEACHERS.

WE EXPECT THIS TO CHANGE OVER THE NEXT YEAR. AS THE PROGRAM OBJECTIVES BECOME MORE CLEARLY DEFINED THROUGH THE PLANNING PROCESS MORE FOCUSSED PROPOSALS WILL BE SUBMITTED AND FUNDED.

BUT AT THIS POINT, WE CAN PRUDENTLY OBLIGATE ONLY $50.5 MILLION IN THE PRECOLLEGE PROGRAMS IN 1985. THUS, WE ARE PROPOSING THE $31.5 MILLION DEFERRAL AS A PLANNED CARRYOVER IN 1986. WE BELIEVE IT IS GOOD MANAGEMENT TO CARRY FORWARD FUNDS THAT WE WILL NOT BE ABLE TO OBLIGATE IN 1985.

CONCLUSION

MR. CHAIRMAN, THIS IS A TOUGH BUDGET YEAR FOR EVERYBODY. HARD DECISIONS HAD TO BE MADE IN THIS ATMOSPHERE, AND IT IS SOMETIMES DIFFICULT TO FOCUS ON PROGRAMS WITH LONG-TERM PAYBACKS; BUT THAT IS OUR OBLIGATION.

THE PRESIDENT HAS MADE HIS DECISIONS, AND THE FOUNDATION HAS FARED WELL. THAT'S IMPORTANT BECAUSE THIS ADMINISTRATION CONTINUES TO BELIEVE, AS I DO, THAT BASIC SCIENTIFIC AND ENGINEERING RESEARCH IS ESSENTIAL FOR CONTINUING ECONOMIC GROWTH, MAINTAINING THE NATIONAL SECURITY, AND IMPROVING OUR QUALITY OF LIFE.

WE TAKE THIS RESPONSIBILITY VERY SERIOUSLY. WE EVALUATED OUR PROGRAMS AND PRIORITIES AND ALSO HAD TO MAKE SOME HARD DECISIONS. WE HAVE FORGED THIS PROCESS INTO A 1986 REQUEST WHICH MAINTAINS THE MOMENTUM IN NEW SCIENTIFIC AND ENGINEERING RESEARCH, BUILDS A STRONG FOUNDATION FOR SCIENCE AND ENGINEERING EDUCATION, AND ACHIEVES AN OPTIMAL BALANCE BETWEEN INVESTIGATOR, GROUP AWARDS, AND LARGE FACILITIES. IT IS A PRECARIOUSLY BALANCED BUDGET; THERE ARE MANY INTERLOCKING AND INTERDEPENDENT PROGRAMS AND PROJECTS.

THIS BUDGET REQUEST ALONG WITH YOUR CONTINUED SUPPORT SIGNALS STRONG COMMITMENT TO KEEP U.S. SCIENTIFIC AND ENGINEERING RESEARCH AND TECHNOLOGY THE WORLD'S BEST.

STATEMENT OF DR. ROLAND W. SCHMITT, CHAIRMAN, NATIONAL SCIENCE BOARD

Mr. Chairman and Members of the Subcommittee,

I am sorry not to be able to be present at your hearing on the National Science Foundation's FY 1986 budget and would like to present a statement for the record. I will summarize some of the science and engineering policy issues that bear on the strategy behind this budget, and some of the priorities it addresses.

Today the Nation faces heightened international competitive challenges--economic, military, and technological. This competition broadens demands on science and engineering research and education. These pressures make it more important than ever before to strengthen the science and engineering base that underlies all our technology efforts. That base determines the ability to perform forefront research, and to renew the Nation's supply of first-rate scientists and engineers. But at the very time demands are greatest, we face the prospect of deteriorating research and education capabilities in our great universities, due to shortages of faculty and of up-to-date equipment for instruction and research.

The Federal Government plays the leading role in supporting universities in their efforts to do research and provide personnel for the future. So, even in a time of necessarily constrained budgets and hard choices among many worthwhile goals, the President's FY 1986 budget attaches priority to the continuing need for strengthening the academic science and engineering base on which the Nation's economic and military security depend.

This need is being met by several recent initiatives that provide new environments and capabilities for strengthening research and education. The National Science Foundation has begun the process of creating Engineering Research Centers--a new form of university-industry cooperative research effort that puts cross-disciplinary teams of engineering faculty and undergraduate and graduate students to work on problems that combine intellectual excitement with economic value. The concept has received strong support from the President's Science Advisor, the National Science Board, the National Academy of Engineering, and industry. I urge your continued support of this new concept for gaining fundamental engineering knowledge while educating future engineers.

Another such initiative is the plan to establish advanced scientific computing centers, to enhance progress in many areas of science and engineering research and education. The computing revolution has created dramatic improvements in all aspects of doing science and technology, from experimentation to computer modeling to computer-aided design and engineering. Strengthening the science and engineering base requires making sure the next generation of scientists and engineers can use these tools. The proposed centers were judged in part on their close involvement with high quality research projects and their educational value in teaching students and researchers to use the most advanced computers.

Universities continue to experience severe problems in obtaining state-of-the-art research instrumentation. In response the NSF is continuing to increase support for instrumentation on all levels, from individual projects and investigators to national centers serving hundreds of scientists and engineers. First-rate instrumentation is essential, both for research and for the education of tomorrow's innovators and investigators.

Another major initiative, the Presidential Young Investigators Program, addresses the problem of faculty shortages. Universities need outstanding scientists and engineers in teaching positions if they hope to turn out outstanding graduates in science and engineering. But retaining those teachers is difficult, given the high demand for their skills in non-teaching jobs. The Presidential Young Investigators Program provides a big incentive for staying in teaching--NSF research funding and matching industrial support up to a total of $100,000 a year for five years. The Nation's engineering and science communities and its advanced-technology industries strongly support this program, and I urge your continued support for it.

Science and engineering education also needs strengthening, particularly at the precollege levels. As many of you know, this need has been voiced in many recent reports. The NSF is responding with new efforts to strengthen its science and engineering education programs. The National Science Board strongly supports those efforts.

And, finally, the past decade has witnessed a phenomenal expansion in biological science and technology. Continued American leadership here will depend on the strength of the science and engineering base. In response, the NSF is undertaking an initiative that will support biotechnology-related research underlying such goals as the improved growth and utilization of food and fiber crops, better medicines and diagnostic techniques, and improved production of specialty chemicals. The initiative will also support the education of the bio-engineers needed to assist the turning of basic knowledge into practical processes and products.

These are some of the initiatives meeting what I regard as the NSF's top priority--strengthening the Nation's science and engineering base. I would also like to note that the National Science Board this past month approved a report and statement on the issue of educational institutions attempting to bypass merit-based review through the legislative process. The Board made three recommendations:

(1) It urged the Director and members of the National Science Board to continue to speak out on the self-defeating consequences of circumventing the merit review system, and urged all professional societies, associations, academies, industry researchers, faculty and principal investigators to act in concert and support merit review.

(2) It asked the Director to appoint a committee to review evaluation processes within the NSF, review other agencies' approaches and recommend any modifications that it judges desirable. The committee will analyze how comprehensive merit review applies to diverse activities, such as general research grants, instrumentation awards, and special programs (e.g. international, women and minority programs).

(3) It called for a conference on Academic Research Facilities to be sponsored by the NSB, the National Academies, and the Office of Science and Technology Policy. The conference would draw on talent from the financial community, the Congress, state governments, federal agencies, academic institutions and business to define the problem and propose solutions. Emphasis would be placed on identification of novel financial approaches available to state governments and universities.

A copy of the Board's statement is attached to this statement.

Let me conclude by describing how we have restructured the National Science Board to increase its involvement in developing NSF policy, and in national science policy in general.

To help the Foundation respond to human resource needs more effectively, we have established a Committee on Education and Human Resources to oversee the Foundation's efforts in science and engineering education. It will also address science and engineering personnel issues, including efforts to bring minorities, women, and the handicapped into science and engineering careers.

To oversee NSF long-range planning and program implementation more effectively, we have established a Committee on Programs and Plans. We want to move away from reliance on approval of awards as the primary mechanism for NSB oversight of NSF programs. We believe that by reducing the number of individual grants we are required to review based solely on the dollar limit, we can spend more of our time reviewing programs with special policy significance, such as the initiatives I spoke of previously. And we will be able to get involved earlier in the decisionmaking process.

We have worked very closely with Erich Bloch in devising the recent changes in the Board's structure, with the aim of involving the Board more fully in the substance of the Nation's science and engineering policy level problems, opportunities, and issues. The National Science Board can only be as effective and useful as the Director wants it to be. This Director has made it very clear that he wants an active, strong Board. It is a pleasure to work with him.

Finally, let me give you some examples of the tasks the Board will take on during 1985. At the broadest level, we will work with the Director to develop NSF's goals, organizational philosophy, and future program directions. We will also examine changes in the institutional framework for supporting university-based science and engineering, NSF's role in fundamental computational science in relation to other agencies, and the development of the initiatives I just reviewed--science and engineering education, engineering research centers, advanced scientific computing, and so on. We will also continue our reviews of science in the international setting, and of research excellence and the breadth of research participation. The question of how we can foster and maintain excellence in our research universities in the context of national needs and priorities is one that we must all address.

The Board looks forward to working with Erich Bloch as he tackles these tasks and implements the strategic directions for the National Science Foundation that you have supported in recent years.

FISCAL YEAR 1986 PRIORITIES

Mr. BLOCH. Mr. Chairman, this is a very tight budget year, and we have fared well in considerations leading up to the President's budget submissions to the Congress. This speaks well for the administration's and also the Congress' support for the U.S. scientific enterprise.

We had hard choices to make, and choices reveal much about one's priorities. Our first priority is to maintain and improve the health of basic science and engineering research. We also realize how important basic scientific and engineering research is to U.S. industry in terms of international competition, new processes, materials and equipment, and to its ability to stay ahead of rapid advances in new and emerging technologies.

These concerns led us to give priority to three major areas in developing the 1986 budget. First, we increased support to programs that were most directly related to economic competitiveness. Engineering is a prime example, but also included are other areas such as biotechnology, Earth sciences, and advanced materials.

Second, we will continue to improve the infrastructure of science in universities. By "infrastructure," I mean people, equipment, and facilities that are integral to research. And in the order of priority, people are first, instrumentation and equipment second, and facilities third.

Through research grants we are supporting over 14,000 graduate students, a 4-percent increase over last year. In addition, we support over 1,500 graduate fellowships, 500 Presidential young investigators, and about 14,000 senior scientists.

Support for instrumentation is up 15 percent to over $270 million. That is about 20 percent of our research and related expenditures.

Facilities such as the recently announced supercomputer centers will be available to a large number of academic researchers.

The third priority area involves activities for which NSF has a special responsibility, such as mathematics, environmental biology, and social and economic sciences, for example.

PROGRAM ADJUSTMENTS AND HIGHLIGHTS

Given these priorities and an austere budget year, we had certain other decisions to make. We are curtailing certain programs that are no longer in the mainstream of scientific and engineering research or are of lower priority. We are stretching out large capital investments to conserve money and lowering administrative costs. We are also continuing a strong effort to leverage funds by increasing participation from and cooperation among universities, the States, and industry.

I would like to give you a few highlights: Obviously, the core research area is a dynamic assembly of programs. We took a hard look at these programs as part of the 1986 budget preparation and reduced or terminated funding for programs that are no longer competitive.

With the freed-up funds, we have provided for exciting new research opportunities in areas such as biotechnology, materials research, and ocean drilling.

We will continue to make these evaluations and make hard decisions to assure Congress and ourselves that the best, most promising research opportunities are properly funded.

Several initiatives started, and well underway to support the predominantly undergraduate institutions, have reached the requested level of about $44 million in fiscal year 1986. The Presidential Young Investigator Program will increase to about $30 million and add 100 new young investigators, bringing the total number supported to 500.

Support for advanced scientific computing is increasing to $46 million to provide scientists and engineers with access to supercomputer centers and supercomputer capabilities. We have announced four of these centers so far, and a fifth one is under consideration.

Support for engineering research centers will climb to $25 million. There will be up to 10 such centers by the end of 1986. We will have our first announcement next week.

SCIENCE AND ENGINEERING EDUCATION

I need to single out and discuss in more detail our effort in the science and engineering education area. Prior to 1982, precollege- and college-level activities at NSF had numerous underfunded and fragmented programs. They were not adequately coupled to State and local programs. Since 1983, we have been rebuilding this area to provide leadership and serve as a catalyst in developing course materials, innovative teacher activities, and support for out-of-school activities. This funding has increased from about $1 million in 1983 to about $50 million in 1985 and the same for 1986.

Gearing up, from an operational standpoint, takes time, if one is to build a cohesive program that is effectively coupled with State and local efforts while maintaining a high standard of excellence. The staffing needs had to be addressed, and the staff is in place now.

We are building a comprehensive, long-range plan to deal with these issues and make sure that our efforts are effectively coupled to the $144 billion investment in education by other Federal agencies and by State, local, and private sources. We are a small, but very important, part of this total effort.

In the science and engineering education community, like research, stability is critical for excellence, and that is what we are trying to achieve. We have funded excellent proposals, but even a collection of excellent proposals does not necessarily make for a cohesive program.

For these reasons, we can prudently spend only $50 million this year. We plan to carry over, in the form of a deferral, $31.5 million in the precollege area from 1985 to 1986 and give the programs the continuity and stability that they deserve.

In addition to that, we have a College Instrumentation Program of $5 million, with matching funds from other sources to make for a total of $10 million, and we are continuing to maintain 1,500 fellowships in 1986.

These 1,500 graduate fellowships have increased their stipends to about $11,000 a year, double the amount of just a few years ago.

SUMMARY

In summary, Mr. Chairman, much discussion and many hard decisions have gone into formulating this request. As a result, it represents a balanced and integrated approach, a balance between single investigators and large facilities, between human resources and equipment, between traditional research activities and critical and emerging areas. We believe the strategy is essential for maintaining and improving an increasingly complex scientific enterprise. It is a strategy that speaks to the future, not just the present. The ideas, people, and equipment that we support today will provide the science and engineering leadership of tomorrow.

Thank you very much for giving me this opportunity.

MR. BLOCH FIRST NSF DIRECTOR FROM INDUSTRY

Senator GARN. Thank you very much, Mr. Bloch.

Mr. Bloch, you are the first Director in the National Science Foundation's 35-year history to come from industry. By all accounts, you have had a very distinguished career as an industrial research and development manager. In fact, I would like to congratulate you on receiving the first National Technology Award from the President just last month. I understand that was made because of your participation in the development of the IBM 360 computer.

Your background in the development, application, and dissemination of technology is impressive. With 7 months of Government service under your belt, I hope you are not too discouraged with what you have found out so far. [Laughter.]

I asked Senator Lautenberg, who has a similar private-sector background, the same question some time ago: With a very distinguished career in business, how was he faring with the great wonders of the wizards of the Potomac here in Washington? So I hope you are not discouraged at this point.

PROPER FEDERAL ROLE IN SCIENCE AND ENGINEERING

But, coming from your background in industry, can you share with us your view of what the Federal role should be in science and engineering?

Mr. BLOCH. Yes. Thank you, first of all, for your congratulations. Let me assure you I am not at all discouraged. In fact, quite to the contrary. I find that the Foundation has outstanding and excellent people who are dedicated and carry a heavy workload. They are in the forefront of technology and, more importantly, they are very responsive to leadership.

I was told before I came here that you pull on the string and nothing happens at the other end. Let me assure you that that is not my experience. I have pulled on strings in industry many times and nothing has happened. [Laughter.]

So I am looking forward to this assignment, and I am highly encouraged.

Now to turn to your question, I think the Federal role is a very important one, and the Federal role can best be emphasized by essentially focusing on basic research and on fundamental research and making sure that the support we are giving to universities is for that purpose, because through it essentially we can determine the long-term effect of research.

Research takes a long time to come to fruition. The incubation period is long. As a consequence, I think, if the Federal Government focuses on basic research, an area which is very costly and has a lot of risk associated with it, then I think that is the best way we can influence the future of our industry, or industries, and the future of the country.

NEW RELATIONSHIPS DEVELOPING

By the way, I am seeing new relationships developing between industry, academia, and the Government. I think, for many of the cooperative programs that we are undertaking, like Presidential young investigators, which require industry support, much of the funding that flows into universities today is something new, or it is at a much higher level and more intensely done than it was in the past.

So I think industry recognizes the university as not just being an education factory, so to speak, but also the supplier of basic research. I think industry also realizes in the universities an underutilized resource.

So I see a lot of new relationships developing, not just between universities and industry, but also between industry, universities, and the Government. I think we need to support that.

CHOICE OF SUPERCOMPUTER CENTERS

Senator GARN. During the selection process of the recently announced supercomputer centers, an issue was raised over the possible selection of an applicant which would utilize a foreign designed and assembled machine.

Do you believe the nationality of that supercomputer is a factor in your selection decision?

Mr. BLOCH. Let me be very precise on that particular subject. When the peer review took place on the 20-odd proposals for the super computer centers, that item was not a point of discussion or point of evaluation at all. What was under discussion and what was evaluated was the basic plan: How credible is it? How important is it? What can that particular interactive configuration do? It is not just the computer but all the other things that supported it. How important is that configuration for the science and engineering people that are using it, and what kind of support can be given from that particular center? Those were the only selection criteria.

It just so happened that the Japanese computer did not come out on top. In fact, it came out at a level that was far down, and the funding we had available cut off short of that particular proposal. The peer review definitely did not take the place of origin into account at all.

Now I will be very forthright on that subject. However, if it had happened that that particular proposal involving a Japanese computer were the first or second or best, I, as the Director, would have had a problem. Let me tell you exactly what I mean by that.

Reading and reviewing the super computer initiative as it was approved by Congress last year, I got the succinct impression that two things were on Congress' mind. No. 1 and foremost was a desire to supply this kind of tool to our researchers in universities. That was the foremost reason. That is a very important tool to do research now and in the future.

Second, I also got the impression that the sense of the Congress was that, by doing that, we would support the domestic industry, the supercomputer industry, and give added impetus to the development of better products, more products in the future, and keep developing this very important and strategic capability.

Taking those two things into consideration, I would have had a problem in making a decision. But let me say that, because of the evaluation results, this last point is academic.

I was lengthy in my answer. I apologize for that. But I thought you should know the total story.

Senator GARN. No, it is nice to have witnesses who have answers. [Laughter.]

Mr. BLOCH. I hope I can continue.

Senator GARN. Sometimes the questions are poor and the answers are poor, too. But no, we appreciate it. You, obviously, in a limited length of time, have been very deeply involved from your answers so far. We appreciate that.

ADDRESSING CONCERNS OF ENGINEERING COMMUNITY

There have been concerns expressed in the engineering community that in the past this discipline and profession was not adequately addressed by NSF. With your appointment, and many of the new directions included in your fiscal year 1986 budget involving engineering, I would suspect that the concerns of the engineering community are being addressed.

Would you share my assessment of that?

Mr. BLOCH. I would hope so. I am not absolutey sure.

By the way, let me say one thing. I agree with some of the comments that have been made in the past, that engineering did not get the emphasis that it deserved. I also want to say that the emphasis on engineering today is quite different than it would have been 10 or 15 years ago, because the importance of engineering has increased; also, the fact that much of what engineering is today is highly science-based engineering, which was not always the case in the past.

The whole environment for engineering has changed. So it is not just that I came to NSF with an engineering background, but I think forces that are at work in the engineering research area would have focused the Foundation in this direction anyway.

Let me make sure I am very clear on that. I don't want to further engineering at the cost of science. The two have to move together. It is a continuum. Science and engineering is a continuum. The big cleavage between science and engineering, that some people talk about I don't subscribe to, and I don't think it represents reality. It certainly doesn't represent the reality today. We have to strive for a good balance between the two and make sure we don't further one at the expense of the other. Both of them have to be furthered.

IMPLEMENTATION OF EDUCATION FOR ECONOMIC SECURITY ACT

Senator GARN. Last year Congress passed the fiscal year 1985 NSF appropriations before enacting the Education for Economic Security Act. As a consequence, the provisions of that act relating to NSF have not been funded, although ongoing NSF education programs parallel much of the activity envisioned in the authorizing legislation.

Can you highlight your views in this regard, especially directions raised by that legislation with which NSF disagrees?

Mr. BLOCH. Yes, I will be glad to do so.

Let me say that I have spent more time on this particular subject of education than on any other subject since I have been here.

As you said yourself, the act was not followed by appropriation and, therefore, we could not implement the act. But, on the other hand, there were provisions in the act which are reflected in our programs and have been reflected in the appropriations we have received from Congress.

There are many things that we are implementing that implement the spirit of that particular act. Encouraging cooperation between universities and State and local educational agencies is certainly one of them. Encouraging cooperation between education departments and mathematics and science departments in universities is another one. Supporting teaching institutes, supporting partnerships, and activities involving cost sharing between Federal, State, and private sources is another one.

Our programs are not as prescriptive as the act was in that particular regard, but, in general, we are encouraging that and we want to further that kind of partnership and cost sharing.

We are encouraging activities oriented toward groups that are underrepresented in science.

So, many of the provisions of the act, we are, in spirit and in many cases in detail, implementing in our programs.

Other things we are not. We are not requiring joint submissions of proposals from the principal investigator and State or local educational agencies. State approval of proposals prior to submissions, thereafter, is not being implemented. We are not implementing precise geographic distribution requirements. Also, I must say the distribution that comes out in the natural and random kind of way is a very good one. We are sensitive to it. But precise geographic distribution we are not doing. And rigid cost-sharing requirements that define exactly a percent of the cost-share, we are not doing that either. So that is about where we are. Essentially in many things with that particular act, we are not only in agreement but are doing them. Other things that are very prescriptive, we are not implementing, and we would have a difficult time accommodating ourselves to that particular requirement.

Senator GARN. Do you support reauthorization of the legislation?

Mr. BLOCH. No, we don't; not in the way it is right now, but we are working with that particular committee to see what can be done, and we are regularly in touch on this particular subject.

I have talked with the staff, myself, and made it clear that we want to work with the committee to make that particular act a better one for all of us.

COMPARISON OF NSF ACTIVITIES AND PROVISIONS OF ACT

Senator GARN. Would you supply for the record a detailed comparison between your activities and those authorized in the act?

Mr. BLOCH. We have such a comparison. We would be glad to supply it for the record.

Senator GARN. Thank you.

[The information follows:]

DETAILED COMPARISON BETWEEN NSF ACTIVITIES AND THOSE AUTHORIZED IN PUBLIC LAW 98-377

NSF Programs and PL 98-377

Title I, Part A
Section 101

Grants for teacher institutes authorized.

NSF Program:

The Science and Engineering Education Directorate through its Division of Teacher Enhancement and Informal Science Education supports the following programs for the continuing education of teachers:

- Leadership activities for precollege teachers; and

- Local and regional teacher development.

The focus of the NSF's teacher development activities is to help identify outstanding science and mathematics teachers, to help develop master teachers, and to encourage creative model programs for continuing education of teachers. This focus is a manisfestation of NSF's new policy "To create a continuing National capability to maintain and renew excellence in mathematics, science and technology education." It is not the Federal role to retrain all the teachers that need retraining. Through its activities, the NSF is helping the science and mathematics education community develop the resources necessary to carry out most of this renewal on its own.

Section 102(A)

Each local educational agency and institution of higher education, and each State educational agency and institution of higher education desiring to receive a grant under this part shall submit a joint application.

NSF Program:

The NSF proposals may be submitted jointly or separately by institutions of higher education, State and local educational agencies, non-profit and private-profit organizations, museums, professional societies, science academies and centers and other institutions with a scientific or educational mission.

The NSF strongly encourages collaborations and partnerships at all levels of program development. These include joint planning and formulation of projects.

The long-term well being of mathematics, science and technology education in this country will be most effectively enhanced by meaningful collaborations among eligible entities.

NSF will publish periodically a listing of funded projects in leadership activities and local and regional teacher development to provide information to prospective teacher participants, as well as examples for others who wish to develop similar partnership efforts.

Section 102(B)(1)

Each such application shall describe the establishment and operation of a teacher institute.

NSF Program:

Over the years the NSF has developed a streamlined proposal submission form, Grants for Scientific and Engineering Research (GSER), by which proposing entities can be assured of meeting all fiscal and accounting requirements in the grants process.

The Directorate for Science and Engineering Education requires the use of the GSER for all proposals submitted for its programs.

At the program level, additional information is requested which will show whether the proposal meets the overall policy objectives of the Directorate.

Section 102 (B)(2)

Provide assurances that the design and operation of the institute will involve the participation of both the subject matter departments or divisions of each institution of higher education making application as well as the teacher education department or division, if any, of each such institution.

NSF Program:

NSF's teacher enhancement programs encourage interaction between departments within an institution of higher education submitting a proposal.

The NSF recognizes the importance of the colleges of teacher education in the training of classroom teachers. On a broader policy level, the Directorate strives to strengthen the relationship among subject-matter departments and colleges of education within institutions of higher education. NSF is promoting true collaborative efforts between the practitioners of science, engineering, and education.

To aid in these efforts the Directorate's Advisory Committee omprised of 20 members, has been chosen to represent scientists, engineers, and science educators. Currently, there sits on the Advisory Committee a dean of a college of education, three professors from colleges of education, a school superintendent and a high school teacher.

Section 102(B)(3)

Provide for prior and continuing consultation with the State educational agency.

NSF Program:

State educational agencies have prior and continuing consultation with proposers in most precollege science education programs under the Executive Order 12372 process.

On October 1, 1983, an intergovernmental review program, established by Executive Order 12372, went into effect. The Directorate for Science and Engineering Education monitors proposals to ensure that states have had the opportunity to review programs for which Federal funding is being sought.

Currently, 30 states have elected to review proposals submitted from their state. Every state may elect at the beginning of each fiscal year to participate in the intergovernmental review process. An election not to participate is binding until the beginning of the next fiscal year.

The Directorate is exercising leadership in this area through continuous contact with the Council of Chief State School Officers and representatives of other professional associations within the educational, mathematics and scientific communities. These efforts will further contribute to the successful rebuilding of an effective National capability in mathematics and science education by bringing together sectors that have not traditionally been involved in NSF activities.

Section 113(A)

Director shall assure that there is an equitable distribution of institutes.

NSF Program:

The following table provides data on proposals and awards for FY 1985 through April 1, 1985:

	Proposals		Awards		Pending	
	#	$,M	#	$	#	$
FY 85 Leadership Activities	161	32	22	3.5	88	20
Local & Regional	355	113	49	7.4	201	61

The NSF provides funds for merit-based competitive awards.

The NSF strives to achieve wide distribution in the impact of its other funded programs.

The NSF is committed to funding teacher enhancement projects that will have the widest applicable outreach.

The NSF anticipates that many State and local educational agencies will use funds received from Title II of PL 98-377 and Chapter 2 of the Education Consolidation and Improvement Act, as well as other sources, to enable teachers to attend NSF-funded activities. In this way, the impact of NSF leadership will be further expanded.

The NSF will provide the Department of Education with a list of funded teacher workshops that will occur during the Summer of 1985.

In turn, the Department of Education will provide the list to the 50 State educational agencies and, through them, to the 16,000 local educational agencies.

Section 113(B)

No grant to a single applicant may exceed $200,000 in any fiscal year.

NSF Program:

The NSF program does not place limits on any of its teacher enhancement awards.

Limits would be disadvantageous to improving the quality of teacher education in science and mathematics education across the Nation.

Many excellent teacher enhancement proposals have been received that have far-reaching outreach possibilities, both intra- and inter-state. Many of these proposals have budgets that exceed $200,000. For example, in FY 1984 NSF received 183 proposals with an average request over $300,000.

The NSF has provided teacher enchancement awards in excess of $200,000 where it is clear that the project will further the goal of providing excellent teacher enhancement that would otherwise be unavailable.

Section 114

Institutes assisted under this part may, to the extent possible, involve the cooperation of advanced technology business concerns and other business concerns.

NSF Program:

The NSF is committed to encouraging partnerships between educational institutions and agencies and business and industry in support of teacher enhancement programs.

Partnerships are an important ingredient in sustaining continuing education programs for teachers.

The NSF budget for science and engineering education represents a relatively insignificant percentage of the total annual expenditure for elementary and secondary education across the Nation.

Thus the NSF is committed to exercise leverage in establishing partnerships in science and engineering education.

NSF programs are a framework which mathematicians, educators, scientists and engineers can use in developing innovative and up-to-date proposals that will address identified needs in science and engineering education.

The Federal role is of necessity limited. The long-term success of NSF-supported projects will depend upon support from business and industry, State and local governments, civic organizations, non-profit entities and volunteers.

Section 115

Meet the needs of underrepresented and underserved populations.

NSF Program:

The NSF is attempting to address the needs of the underrepresented and the underserved in all its programs.

The NSF is committed to the full participation of women, minorities and the physically handicapped in all of its programs. Other factors ~~being~~ substantially equal, NSF gives preference in the selection of its awards to those that will most effectively increase the participation of women, minorities, and the physically handicapped in science, mathematics and technology education.

In addition, the NSF provides assistance for pre-proposal submissions where the proposer requests such.

The Foundation collects data for each proposal which will show the participation of women, minorities and the physically handicapped in the program funded.

Part B, Section 121

Enter into agreements with institutions of higher education or local educational agencies for (1) developing and disseminating programs and materials for training and inservice training for elementary and secondary school teachers; and (2) the research, development, and dissemination of instructional programs and materials in the fields of mathematics, science, including physical and life sciences, and computer learning.

NSF Program:

The Directorate for SEE, through its two divisions, Materials Development and Research and Teacher Enhancement and Informal Science Education, supports research, development, and dissemination of instructional programs and material at the precollege level. The NSF programs enable institutions of higher education and local educational agencies to participate jointly in planning, developing, and implementing these projects.

NSF program guidelines invite proposal submission from all colleges and universities, State and local educational agencies, professional societies, science museums and zoological parks, research laboratories, private foundations, private industry and other public and private organizations, whether for profit or non-profit.

This expanded eligibility encourages interaction among entities whose expertise and experience positively contribute to the development of materials and resources in precollege science and mathematics education. NSF has developed a program in research in teaching and learning, for which proposals are sought that will expand the understanding of the cognitive process.

This program supports basic and applied research on significant factors that underlie effective teaching and learning of precollege science, mathematics, and technology.

Anticipated outcomes include knowledge of:

- How students learn complex concepts in science and mathematics;

- How students learn to apply these concepts effectively in real, problem-solving situations; and

- Those factors that are most influential in governing the student's participation and performance in school science and mathematics courses.

An understanding of the cognitive process is important--particularly at the precollege level--if the subject-matter impact is to be effectively communicated to the precollege student.

Section 122(A) and (B)

Each application shall contain assurances of cooperation between institutions of higher education and State or local education agencies, science and education departments, and where appropriate scientific societies.

NSF Program:

The Science and Engineering Education Directorate through its Division of Teacher Enhancement and Informal Science Education supports the following programs for the continuing education of teachers:

- Leadership activities for precollege teachers; and

- Local and regional teacher development.

The focus of the NSF's teacher development activity is to identify outstanding science and mathematics teachers, to develop master teachers, and to encourage creative model programs for continuing education of teachers. This focus is a manifestation of NSF's new policy "To create a continuing National capability to maintain and renew excellence in mathematics, science and technology education." It is not the Federal role to retrain all the teachers that need retraining. Through its activities, the NSF is helping the science and mathematics education community to develop the resources necessary to carry out most of this renewal on its own. The NSF peer review process and NSF professional staff analysis assures that cooperation between and among the stated groups is present in projects as appropriate.

Section 123

Meet the needs of underrepresented and underserved populations.

NSF Program:

The NSF is attempting to address the needs of the underrepresented and the underserved in all its programs.

The NSF is committed to the full participation of women, minorities and the physically handicapped in all of its programs. Other factors being substantially equal, NSF gives preference in the selection of its awards to those that will most effectively increase the participation of women, minorities, and the physically handicapped in science, mathematics and technology education.

In addition, the NSF provides assistance for pre-proposal submissions where the proposer requests such.

The Foundation collects data for each proposal which will show the participation of women, minorities and the physically handicapped in the program funded.

Part C, Section 131

Congressional Merit Scholarships in Mathematics, Science, and Engineering Education.

NSF Program:

The NSF has not established a Congressional merit scholarship program.

Title III

National Science Foundation Program for Partnerships in Education for Mathematics, Science, and Engineering.

NSF Program:

The Foundation has not established a separate program for partnerships in education. NSF is, however, committed to promoting partnerships in its programs as is evidenced by the references to partnerships in the program guidelines. The guidelines invite proposers to work together with other eligible entities in developing proposals to be submitted to the Foundation.

The NSF allows, but does not require, partnerships in the precollege science and mathematics education programs. The College Science Instrumentation Program does require a match of a minimum of 50 percent non-Federal funds.

The Foundation has hired a business-industry liaison person. This individual comes from industry and has a broad understanding of industry support for science and mathematics education programs. The NSF will attempt to broaden its outreach efforts to business and industry by informing them of the NSF programs in precollege science and mathematics and college science instrumentation. Through these contacts, the Foundation hopes to articulate the importance of industry and business participation in the ongoing efforts to address the problems in science and engineering education.

The NSF is concerned that the percentage matches prescribed in the partnership program under Title III may actually serve as a disincentive to partnership formations. For example, business and industry is less interested in supporting projects where, a priori, there is a stated minimum industry match. Such matches often give the impression that a project has been pulled together and its success is dependent upon industry contribution of a minumum percentage. Business and industry tend to look askance at such requirements, and would rather review the merit of the proposal and fund the amount most appropriate for them.

Much of Title III appears to be written in a manner similar to the partnership provisions of the Job Training Partnership Act. The Foundation would like to work with the Hill staff to develop a partnership program that more clearly applies to the science, mathematics and education system in the country.

Title IV
Section 401

Presidential Awards for Teaching Excellence in Mathematics and Science.

NSF Program:

The Foundation has made Presidential Awards for Excellence in teaching science and mathematics to high school teachers who have demonstrated outstanding teaching qualifications for the past 2 years.

The prestige associated with the Presidential Awards provides National recognition for excellence in science education and the backgrounds and accomplishments of the awardees are publicized as an example and incentive for others.

IBM 360 COMPUTER

Senator GARN. Senator Lautenberg?

Senator LAUTENBERG. Thank you very much, Mr. Chairman.

Interestingly enough, Mr. Bloch, if I might for just a moment digress, my former company, ADP, was among the earliest users of the 360 equipment. We first started to get delivery in 1965. I wonder if you know that 360's are still—I believe this is still the case—on the commodity control list because the technology is so essential. It is a bit of a joke. You can't give them away today. Wonderful machines. But we try to give them to charities because the maintenance is more and we can't sell any abroad because we don't want our enemies to find out our secrets. [Laughter.] But they did find out some had gotten out of the country when the Soviet Union sent them back for repair. [Laughter.] That is true, by the way.

Senator GARN. Hopefully, they are that far behind us. [Laughter.]

ADVANCED SCIENTIFIC COMPUTING—FUNDING ADEQUACY

Senator LAUTENBERG. Mr. Bloch, I am pleased to have a chance to see you here and meet for the first time. I hope that our contact will be frequent.

I have an interest, as you can imagine, in the National Science Foundation and wish it well. I would like to see, frankly, budgets that fulfill its mission as opposed to the condition we find ourselves in where we do have to cut back and deal with the whole budgetary problem.

NSF has requested $46 million for advanced scientific computing. As you would imagine, I strongly support our effort to promote development of super computers and to make them accessible to the research communities.

Centers like the one to be established at Princeton will address the severe shortage of super computing facilities that was detailed by the Lax Panel.

Is the $46 million requested enough to cover the original proposals?

Mr. BLOCH. Before I answer that question, let me just say one thing. I hope your experience with the 360 was better than the Soviet Union's experience.

Senator LAUTENBERG. Ours was excellent. It made a little business for a giant corporation and enabled me to afford the job I presently have. [Laughter.]

Mr. BLOCH. Very good.

Let me answer your question. Is it sufficient? Is it enough? The answer obviously is no, it is not enough. But, on the other hand, it is the best we can do under the circumstances. Also, I believe that we should move carefully in this particular area. Having established four centers in 1985, we hope, with the $46 million, to add another two centers in 1986. We probably need to get between 10 and 20 centers in the ultimate. That is what I would think we would need, if we really want to be in the forefront of this particular area and make this capability available to the science and engineering research community in universities.

COMPUTER UPGRADING ESSENTIAL

We are not going to get there overnight. We have some other priorities within this super computing area. It is not enough to put a super computer center in place. We need to update it frequently, because, as you know very well yourself, this technology moves very rapidly. It doesn't make sense to put a super computer center in place in 1985 and not upgrade it until 1995. It will be surely obsolete halfway during that time period. So we need to put in place, and we have put in place, provisions for upgrading on a real time basis.

The second thing which we have to do is network these systems. A center as a stand-alone center is not very good because it would allow access in only the very localized area.

NEED TO NETWORK CENTERS

What we need to do is to really network these centers in such a way that, no matter where you are in the country, in whatever university, you can get access to a particular center that has a particular——

Senator LAUTENBERG. Mr. Bloch, from the technology standpoint, I feel like a pygmy talking to a giant here, but access is not really the problem. I mean the ability to access doesn't really depend on geography. The question of perhaps data base or particular programs that are being developed I think is a more critical question.

Mr. BLOCH. It is. But, on the other hand, also how one networks is very important so that it is easy for an individual to access the center that he never dealt with before, because each center has its own ideosyncracies. In fact, there are four different machines represented, different activities really represented in these four centers. That should be transparent to the user itself. The important thing is making it easy to use these centers.

So we have to spend a lot of effort and funds to make sure that networking takes place. So we have priorities of establishing new centers, additional centers, upgrading the existing ones all the time, and making sure that the access to them, in terms of networking, is what it needs to be.

Yes, we could use more money, no doubt about it.

Senator LAUTENBERG. If you could fill your wish list and could allow the full funding of these requests, notwithstanding your earlier comment about you can't move as quickly always as you would like to for all kinds of reasons, if you could get full funding, could those funds be put to good use?

Mr. BLOCH. Yes. I will tell you exactly what our initial request to OMB was in this area. It was $60 million. That represented what we thought at that time, unconstrained by other considerations—not completely unconstrained—what we could usefully apply. That gives you a quantitative figure.

Senator LAUTENBERG. Mr. Chairman, I don't know whether you were occupied at the moment, but Mr. Bloch said $60 million was the original request to OMB. So obviously we are responding to the budget crisis.

But it is more than simply a financial setback. This is going to have something to do very definitely with the progress of the program.

Mr. BLOCH. That is correct, yes.

COMPUTING CENTERS CONTRACTS AND COST SHARING

Senator LAUTENBERG. When will the contracts for the centers be signed?

Mr. BLOCH. We have made our announcements. The centers know, the ones that are going to get this particular capability from us and grants from us. We are in the process of negotiating with each one the final details of it. I would think—and I am guessing now—in the next month to 6 weeks that everything would be pretty much buttoned up.

Senator LAUTENBERG. But there are no problems.

Mr. BLOCH. There are no problems. It is strictly making sure both parties understand what is expected of them and what they can expect from the other party, to button down some of the details, and also how we are going to evaluate these centers, which is a very important kind of subject, and what we are expecting of the centers and what the centers in turn are putting forward.

As you know very well, there is a big amount of cost sharing involved in this program. It is not all Federal Government dollars that are going into these centers. The States are putting a lot in, some of the manufacturers in terms of discounts for their equipment and also support in terms of software and people in some cases. So it is a cost-sharing effort.

Senator LAUTENBERG. And universities?

Mr. BLOCH. And some of the universities are contributing to it, very definitely.

Senator LAUTENBERG. There is a great deal of excitement, I can tell you, in our State with the Princeton facility. We expect it to mean a great deal to the industrial capability ultimately of not only our State and our region, but our Nation. I think it is essential.

One of the debates that went on for some time here, I think, was based on a misunderstanding what the super computer meant. The anxiety of making certain we were able to produce it suggested there was an enormous marketplace out there for this. There really isn't. These are very specific applications.

Mr. BLOCH. Can I make one comment on that? Princeton is a very interesting center because it represents a consortium of a large number of universities, close to a dozen universities, far beyond Princeton. MIT is part of it, for example. So it is more than what it does just for that one State and for the schools in that State; it reaches beyond that State.

Senator LAUTENBERG. Of course.

Mr. BLOCH. I think it is important to mention that.

Senator LAUTENBERG. Yes, because we don't want anybody to think that New Jersey got this because of the wisdom or the leadership of its Senator—[laughter]—but, rather, it is a much more purposeful thing, in the national interest.

SUPPORT OF ADVANCED SCIENTIFIC COMPUTING—FISCAL YEARS 1987–90

What do you project the National Science Foundation's support for advanced scientific computing in fiscal year 1987 let's say through fiscal year 1990 might look like?

Mr. BLOCH. That is, again, a very difficult question to answer. First of all, we have to understand a little bit better what the environment will be in 1987. I hope it will be better than in 1986 in terms of our total funding. But one can't be sure, so I want to take a very cautious kind of a viewpoint there.

But I would think we should maintain it around that $50 million to $60 million level, which would allow us essentially to continue these centers, and also add centers at a rate of one or two a year. If we could, I would obviously like to up it somewhat beyond that, especially in 1988 and 1989, and maybe reach $100 million eventually. That is a rough assessment.

Senator LAUTENBERG. So the constraints are not in the ability to use these funds wisely or to further the development of these centers and this capability, but it is essentially purely a financial one.

Mr. BLOCH. It is a financial one and it is a balance between the rest of the activities with the National Science Foundation. These centers are not living in isolation. They have to live essentially with the rest of the Foundation. Therefore, we always have this problem of balancing between disparate programs and different kinds of programs, and especially programs that are that highly visible as this one here and demand that much support. So it is a balance question.

ENGINEERING RESEARCH CENTERS

Senator LAUTENBERG. Our Nation's national competitiveness is being challenged more and more. Our expertise in engineering is a critical factor in that ability to compete. NSF is requesting $25 million for engineering research centers; is that correct?

Mr. BLOCH. That is correct.

Senator LAUTENBERG. Can we expect an announcement soon on the selection of a round of applicants for these centers? When might that be?

Mr. BLOCH. We hope that the announcement will come next week. We still have a few minor points to iron out. But I hope that we will be able to announce it by midweek, Wednesday or Thursday of next week.

The proposal has gone through the National Science Board and the National Science Board has approved it, so that is not the problem. We have to straighten out a few administrative details ourselves.

We also want to have some participation by some of the other Government agencies in this particular program. We are trying to wrap that one up also. That would be a very, very good thing to do.

Senator LAUTENBERG. My time is up. I thank you, Mr. Chairman.

Mr. Bloch, it is a delight to see you because of my association with the equipment that you helped develop. It revolutionized, I think, or advanced the capability for computers and computing in our society by a giant step with the introduction of the 360.

Mr. BLOCH. Thank you.

Senator GARN. The Senator is correct, the reduction from $60 million to $46 million is sizable. I will assure Mr. Bloch if you wished to join the private sector, having done so well on the 360, in making a contribution to make up some of that difference, he would accept it and the subcommittee would strike a very nice plaque commending you for that. [Laughter.]

Senator Domenici?

Senator DOMENICI. Thank you very much, Mr. Chairman.

DIRECTOR BLOCH LAUDED BY SCIENCE MAGAZINE

First of all, Mr. Bloch, I want to compliment you on the work you have done thus far. I assume you are aware of the fact that the March 29 issue of Science magazine has paid you a very high compliment by calling you "a forceful new hand on the reins at NSF."

I think their assessment is right. You are the first Director to come from industry, and clearly we look to you for some exciting things. I compliment you and agree wholeheartedly that the efforts that you have begun are going to be worth while for our country. Your experience and understanding of this new age should contribute immensely to NSF and to our country.

The article praises you particularly for the engineering research centers. I have already had an opportunity to talk to you about that initiative. I join in that accolade. I think it is an excellent direction, and I hope we can see it through to fruition with enough resources to do it right.

VLBA AND SACRAMENTO PEAK OBSERVATORY

I want to talk about two or three things that are important to me, and I think important to the country as well. First is the very long baseline array [VLBA]. I think you are aware that this project is the

National Academy of Sciences' Astronomy Survey Committee's No. 1 recommendation and highest priority for ground-based astronomy for the decade of the eighties.

I think you know we have already stretched out the funding for VLBA. I think you are aware of the fact that we have $9 million appropriated, which is a substantial reduction from what the President requested. I think he wanted closer to $15 million.

Last year's appropriation was to be held until April 1 and then released.

I want you to know that I strongly opposed delaying obligation of the first amount of funding to get that major project started. I will take some time with the members of the committee and the chairman to explain why we ought to go ahead with the $9 million that is appropriated.

There seems to be some desire on the part of the Members in the other body to tie this project to some progress, or perceived lack of progress, in math and science education. Frankly, I don't think they are tied at all, and clearly I don't think they ought to be. I would like in a few moments to ask you a couple of questions about that.

Also, I am somewhat confused about the Sacramento Peak Observatory. On March 12 I heard from you that there may be a recommendation to close that solar observatory at Sunspot, NM. Now it is clear to me that everybody assumes that the decision has already been made. I don't know that it has.

I have a great deal of concern as to the practicality of closing it. I don't know how saving $1 million there is worth closing a facility with a present-day value of about $25 million. It is allegedly being considered for closure so another center can be funded and upgraded. I don't see where the $1 million is even going to make a dent in that other project.

IMPLEMENTATION OF EDUCATIOIN FOR ECONOMIC SECURITY ACT

I also want to express my thoughts on science and math education. It is my understanding that because the authorization bill was adopted after the appropriation was enacted, you have understandably had some difficulty in implementing the new law. I am sure that when you reviewed the legislative history, it came as a shock to someone with your background that we don't always do things in a very orderly manner around here. We put the money in an appropriation bill without enacting the bill telling you what to do. I understand that. But clearly I think you ought to be acting on the premise that we are going to reauthorize the Math and Science Education Program. We put in a 1-year authorization too late, but I don't think you ought to assume we are not going to continue that program. The funding level and some of the details may be in question, but clearly I don't think you ought to stand in place because there is some confusion and we need another authorization. You have some responsibility and some money, and I hope you will proceed.

STARTUP ON VERY LONG BASELINE ARRAY

Having said that, let me ask a few questions about the very long baseline array.

Mr. Bloch, is NSF ready to proceed with the release of the $9 million which Congress appropriated as startup money for that project?

Mr. BLOCH. To answer your question directly, the answer is yes, we are ready to proceed.

Let me make a couple of points, one general point and a very specific point. You should know that I am very much in support of that particular program. I think it is a very important program for the astronomy community and for the country as a whole. It represents an entirely different approach to astronomy, and it is a unique kind of capability, once we put it in place. So there should be no doubt where the Foundation stands and where the Director stands on this particular issue.

FUNDING DELAYS

The funding for 1985 has been, indeed, held up until, initially, April 1 of this year. During the hearings in the House, I was asked if I would be willing to extend that date to May 15, and I have agreed I would do so. I think that will give us the possibility of having more conversations on this particular subject, which I think is very important, because I think there are some issues that have not been discussed fully or have not been understood fully.

I am dedicated to making sure that between now and May 15, these discussions will take place, and, hopefully, then, by May 15, we can proceed.

Obviously, this program has had a number of delays already. Last year's reduction represents such a delay. The 6 weeks certainly represent a delay. I am not looking at that as being as serious as last year's reduction in resources, obviously. We can make up for that in the end.

I hope we can move forward with the program that we have been submitting. So I would want to wait now until May 15, have some conversations in the meantime, and then we are ready to move forward and obviously will be ready on May 15 to move forward with it.

Senator DOMENICI. Mr. Bloch, I appreciate your answer.

I also want you to know, and the record to reflect, that I think any delay beyond that which is already a stretchout and a reduction in the initial funding might very well be either implicitly or expressly calculated to kill the project in toto. Clearly this country has to do things like this. We can't delay them forever, especially when they are the highest recommendation of this very important scientific body.

I think you understand the significance of the VLBA project, and we will be working closely with you on it. If there is anything we ought to know or ought to do between now and May 15, we will work with you. I thank you for your answer.

STATUS OF SACRAMENTO PEAK OBSERVATORY

Could I move to the Sacramento Peak Observatory. It is my understanding that Dr. John Jeffries, the Director of the National Optical Astronomy Observatories, made his recommendation that the Sacramento Peak Observatory be closed. Is that the case? What are the justifications, both budgetary and scientific, for this recommendation? I also would like to know whether that recommendation, before acted upon, would receive careful peer review. Will the scientific community that uses the Sacramento Peak facility be part of this peer review? It seems to me unless we have something very significant in mind for the million dollar savings, that we are really giving up a very valuable asset. Would you care to comment, Mr. Bloch?

Mr. BLOCH. Yes, I would be glad to comment on it. Let me make it absolutely clear that the National Science Foundation has not made a decision; in fact, we have not even seen the proposal from Dr. Jeffries. In fact, he has not gone to his board yet. I think that is in the works yesterday and today.

So what you heard—and I felt I was obliged to write a letter to you and other Senators and Congressmen on the subject because that story had leaked out and had gotten quite a bit of attention, as it should. So let me assure you, I have not seen, and no one in the Foundation has seen, an official request. I don't know what the Board will decide when Dr. Jeffries comes in with that proposal or a modified proposal.

Let me assure you that we will obviously look at that one very critically. We are going to involve the community in that and make sure we understand their view.

I have promised the National Science Board—and not only promised, I have an obligation to the Board—to bring that issue before it, whatever the decision is, even if it is a nondecision. So we are pretty far away from talking about closing.

ACCESS TO EXISTING DATA BASES

Senator DOMENICI. I thank you very much. Mr. Bloch, sometime at your leisure I would like an opportunity to discuss with you what is occurring in New Mexico in an effort to develop some models for access to the computer information in our country. We are making some very significant strides in trying to put together a nonprofit organization that would have the capacity to draw on the vast amount of computer information and to ultimately sell it as a service.

We do have within my State, quite by accident, probably the largest array of computers and computer information in the world. We do need input from you because that information is a mixture of public information and very difficult classified information. We need talent such as yours and that of your agency to help us see if we are moving in the right direction to make such information available to the community, to both public and private interests in the country.

Senator LAUTENBERG. Would the Senator yield?

Senator Domenici. Yes.

Senator Lautenberg. With reference to possible sales to the private sector, I would like my good friend from New Mexico to know that a lot of information is available from the private sector. There are all kinds of data bases. Even my old company, just by coincidence, has an interesting data base.

But I know you too well, you wouldn't want to see the public sector competing with the private sector on the sale of that information.

Senator Domenici. No, I wouldn't. I clearly think we are on the cutting edge, however, of tapping the information base that is not available to the private sector. We don't know how to cope with it yet. It is vast and very important. We are trying to get the private and public sector to understand the nature of the problem, and to find some models that will make this service available, not for free but for a charge.

We are well on the way, incidentally, to doing that. The issue is how much access do we get and how do we tie them all together. We are on the way there, too. We may not have Princeton, but Princeton doesn't have a Sandia or Los Alamos lab, either. So we are sharing very serious problems.

We think we have some very solid ideas on how to do this. It is not by way of competition. It is by way of making something that is not presently available, available in an expeditious manner.

Senator Lautenberg. As long as it is not a proprietary—I mean if it can be classified information, of course we in the private sector would never want to sell it.

Senator Domenici. You can't get at it so it isn't a question of selling it.

Senator Lautenberg. I respect my colleague's interest in developing a funding source for information that should be available. But again, I don't think we ought to shortcut any private sector opportunity to make information available. That is ultimately the best way.

Senator Domenici. There is no question about that. You don't have any argument with me on that. I am delighted to have the Senator from New Jersey speaking up in that respect because I am on your side.

Mr. Bloch. I would be glad to discuss it.

Senator Domenici. Thank you very much. Thank you, Mr. Chairman.

Senator Garn. Thank you, Senator.

Senator Proxmire?

Senator Proxmire. Thank you, Mr. Chairman.

Mr. Bloch, welcome to the love-in. Everybody loves the National Science Foundation. Even, in fact, the Golden Fleece goes for the National Science Foundation. I gave you the Golden Fleece some time ago because you were spending money on a study to determine whether pigeons could be trained to follow free market principles or whether they were just hopeless communists. [Laughter.]

I don't know how that turned out, but I think it turned out that they were pretty good capitalists. They were trained to peck in the free market order.

WHY SHOULDN'T NSF BUDGET SHARE IN OVERALL DECREASE?

Let me ask you, the 1986 budget request for almost all nondefense agencies is below the 1985 funding levels. The National Science Foundation's request, on the other hand, appears to be 4 percent higher than the 1985 level. That is $68 million more. Why shouldn't scientists make the same contribution to deficit reduction as everybody else?

Mr. BLOCH. First of all, let me say that obviously we have to contribute; the science and engineering community has to contribute to the deficit reduction like anybody else. It is very important to us also that we put our economy on the right slope and make sure that it blooms and prospers in the future.

I have no problem with that at all. I just would want to say that this particular increase is minimal. As you said, it is 4 percent, 4½ percent.

The second point is that the science and engineering effort is a long-term proposition. We can't expect results overnight. In fact, results don't come overnight. So we have to really look at the total, long-term picture.

I think it is right that fundamental research be given more priority than some of the other areas, in a minimum way, but still in such a way that we can continue and build for the future. I don't think that a freeze that freezes everybody equally differentiates sufficiently and makes allowances for the problem I am citing. A freeze should be more selective, in my opinion.

I know this is self-serving when I am saying that, but it is also my belief that one has to look at the long-term picture. I have been in many freeze situations in the past, by the way, when I was in industry, and it was always on a selective kind of basis. Not everything got frozen equally.

WHY INCREASE ENGINEERING RESEARCH SUPPORT?

Senator PROXMIRE. I think you make, obviously, a strong appeal here, but I am not sure that your budget follows the principles you just enunciated.

In the overview section of the budget you comment that this 1986 budget request, and I quote, "enhances programs where NSF has unique responsibilities."

Now, in this era of tight budgeting, that must mean NSF should concentrate its resources where the private sector is least likely to spend its own R&D dollars. Your budget, on the other hand, proposes a large increase for just those programs important for industry, such as engineering research.

Aren't these areas most likey to be supported by private funding, and why should the National Science Foundation increase the funding for research which will be supported by private funding anyway?

Mr. BLOCH. There is no doubt about it that the private sector funds a lot of research in engineering. But what we are addressing in the engineering research centers is essentially bringing our universities up to the modern era of engineering, upgrading their instrumentation, upgrading their curriculum, upgrading the way engineering has to be taught and done in the future.

Engineering is changing dramatically. This is something that essentially industry can participate in, and we are asking them to participate. Research centers are a cooperative effort with industry. It is not only Federal dollars that we are putting in. But I think somebody has to take the lead. I think it is the Federal Government that has to take the lead because, again, it is education, it is research, it is bringing our universities up to par, and the private sector will not be in a position or will not do it. I won't argue and I can't argue that particular point. I can argue this particular point either way. But I don't think they will be in a position where they are going to do it on their own. So we want to play a leveraging role. We want to point the way. We want to essentially say, here is something that has to be done, that industry will benefit from and participate in. But leaving it up to industry, I know exactly what will happen—nothing.

Senator PROXMIRE. You say leaving it up to industry you know exactly what will happen, which is nothing. Well, that is pretty discouraging. Industry has a self-interest in this. They are going to gain from it. They should contribute to it. Yet, the private sector provides only $1 for every $10 that the Federal Government provides for university research.

Why is private industry's university research contribution so low compared to the Federal Government's contribution?

Mr. BLOCH. I have looked at that area. Let me say two things. First of all, your number is accurate, but I think you have to look one level below that. There are areas of research in universities in which industry participates more than the level that you are indicating, for instance, in engineering itself.

I know of one university where engineering support is approximately 10 to 12 percent. So it varies. It varies among disciplines. It varies among universities. But in the aggregate, your number is right.

I think industry should increase its activity. There is no doubt about it. In fact, I think industrial support has increased over the last few years. But it will never be able to match the big expenditure that the Federal Government can bring forward to this particular area. I don't think that will ever happen.

UPGRADING OF LC-130 AIRCRAFT FOR ANTARCTIC PROGRAM

Senator PROXMIRE. This year you requested $120 million for the U.S. Antarctic Program. That is an increase of 8.3 percent. In your testimony, you mention this money will be used to upgrade two LC-100 aircraft. Do you feel the Antarctic Program must upgrade its program right now or could it research effectively with the same funds as last year?

Mr. BLOCH. Before you came in, Senator, I made the general observation that when we looked at this particular budget, we reduced, to what I call a minimum, the capital expenditures. When we look at the Antarctic Program, upgrading of these aircraft was about what we felt was absolutely necessary. There were other things we had in mind that we would have brought forward if it had been in a different kind of an environment than where this budget is being debated and created.

So we are really asking for minimal funds with the concern we couldn't just put off any longer these upgrades, which should have taken place some time ago.

Senator PROXMIRE. It seems like a lot of money for Antarctica. After all, this would be well over $1 billion in that area. You requested $120 million.

Mr. BLOCH. Right.

Senator PROXMIRE. It is an increase of 8.3 percent. While Antarctica has some scientific promise, it seems to me that that is a lot of money.

Senator GARN. If the Senator would yield for a moment.

Senator PROXMIRE. Yes.

Senator GARN. First of all, $5 million has already been deferred from 1985 to 1986, I believe, so you have had one deferral. But I think this is an area, with all due respect to my colleague, both on this committee and that committee, I have been to Antarctica. That is probably the most hostile flying environment in the world. Believe me, I certainly would not want those C-130's not upgraded.

I would make an offer to my colleague to have one of those long flights to the South Pole with those whiteouts and so on and see if he would feel the same way about those aircraft after having made the flight.

Really, Bill, as far as the aircraft are concerned, and I realize I have a bias toward flying [laughter].

Senator PROXMIRE. You can say that again. [Laughter.]

Senator GARN. You were talking about safety of a lot of scientists and a lot of people. We were down there one day just in helicopters. You can get a whiteout so rapidly, you carry a very large survival kit with you at all times. The sun is bright and there is no wind and suddenly you have 200-knot winds. The helicopter just behind us sat down and had to stay overnight on the ice.

So you are dealing with an entirely different situation. You may want to carry some C-130's in southern California or Florida and say we can get by for another year or so, but the aircraft that are being used down there do a tremendous amount of flying.

When you go to the pole, it is so cold that you don't even shut down the engines. They do not stay at the South Pole. They continue to run their engines. They haul fuel back and forth and supplies to people there. It is a very, very difficult flying situation.

I am certainly not known as a big spender. I have no reputation for being a big spender. When it comes to the safety of those flight crews and all the scientists that they fly to various remote sites around Antarctica, I cannot criticize at all the attempt to upgrade those aircraft.

Senator PROXMIRE. I have great admiration and respect for the chairman. He is a wonderful chairman. He has the same job now I used to have. I used to be chairman of this committee and the Banking Committee. Now he has all the responsibility.

Senator GARN. I hope it stays that way. [Laughter.]

Senator PROXMIRE. We will just have to see what happens in 1986. And I follow the chairman almost anywhere, but not to Antarctica and not to outer space. [Laughter.]

ADVANCED SCIENTIFIC COMPUTING BUDGET INCREASED EIGHTFOLD

Since 1984, the NSF budget for advanced scientific computing has increased by eightfold. I said sixfold earlier, but I was corrected by Senator Lautenberg. Eight times. Hear that Princeton tiger roar.

Can this program successfully manage such a large increase? You know, in the past we have found when we increase a program very rapidly, double it, triple it, in this case eightfold, you have problems with it when it goes that fast. Are you sure you can take that much of an increase in a single year and do it efficiently?

Mr. BLOCH. Increase in a single year?

Senator PROXMIRE. Well, I guess it is 2 years, 1985 and 1986.

Mr. BLOCH. Right. I think that can be done in this particular case. I think the Foundation has shown it can handle programs of this sort.

I think the Foundation has grown over the years and has acquired some knowledge of how to treat it. I don't think I have any problems in that regard.

Senator PROXMIRE. Have you had any experience with a program that big at General Electric, sir?

Mr. BLOCH. I was at IBM.

Senator LAUTENBERG. He wants to know about General Electric first. [Laughter.]

Senator PROXMIRE. In general, isn't it your observation that you can proceed too fast with these things, you can put too much money in, and you don't spend it as wisely as you would if you made the increase over a little longer period?

Mr. BLOCH. I have had increases in programs in the private sector—by the way, it is IBM, not GE.

Senator PROXMIRE. I beg your pardon. I thought you were with General Electric.

Mr. BLOCH. Well, I am not.

Senator PROXMIRE. Well, you get better all the time. [Laughter.]

Mr. BLOCH. I hope I can improve on it.

It depends on the program, you see. It depends on the circumstances. It depends on how prepared the particular group is that is handling that particular program.

I wouldn't want to generalize. Sometimes it is dangerous to increase a program by 25 percent, if you don't have a good foundation and good people in place and know what you are doing and a plan in place. But I have started programs from zero to a few million dollars in 1 year, so that is an infinite kind of an increase. It depends on the subject matter and it depends on the people that participate.

Senator PROXMIRE. $6 million to $46 million in 2 years, that just seems like a very, very sharp, sudden increase.

Mr. BLOCH. You should understand that this particular program is one where we are really giving the responsibility for establishing these groups and centers to the individual contractors or grantees. They have the support in their own shop to do that. They are not starting from scratch. They have experience, and that is why they were chosen. One of the criteria was, how good is the management team.

SPECIAL FOREIGN CURRENCY PROGRAM

Senator PROXMIRE. I just have one more question. In 1984 and 1985, your foreign currency account was about $2.8 million. In 1986 you estimate it will be $1 million. That is a dramatic change in proportion. What happened?

Mr. BLOCH. I need to back off on that one. Foreign currency is a highly technical matter. It has to do with the availability.

Senator PROXMIRE. Can you give us a response for the record?

Mr. BLOCH. I will give you a response for the record. It is a highly technical answer that I have to give.

Senator PROXMIRE. Thank you.

[The information follows:]

SPECIAL FOREIGN CURRENCY

The fiscal year 1986 budget request for special foreign currency represents an overall decrease of 64.8 percent from fiscal year 1985. The decrease reflects a change in the source of funding for research cooperation with India. Starting in fiscal year 1986, plans are to fund such cooperation through the United States-India Fund for Cultural, Educational, and Scientific Cooperation and not through this NSF budget activity. Management of the program by NSF will continue. The requested total amount of $1 million in special foreign currency will maintain a level close to the present level of participation of U.S. scientists and engineers in research cooperation with Pakistan and limited participation in the United States-Poland Joint Board.

PHASING OF VERY LONG BASELINE ARRAY FUNDING

Senator GARN. Senator Domenici?

Senator DOMENICI. Mr. Bloch, let me just talk about the very long baseline array [VLBA] one more time. In the fiscal year 1986 budget request of $11.5 million for the VLBA, it assumes a construction schedule, as I understand it, which has been stretched out.

Mr. BLOCH. Right.

Senator DOMENICI. But it does not assume any major change in the program or any scaling back of the project or other modifications. Is that correct?

Mr. BLOCH. That is correct.

Senator DOMENICI. When you answered me with reference to your voluntary willingness to hold up funding until May 15, did I understand you correctly that that is for purposes of discussion and clarification, but that on May 15 you intend to release the money made available by Congress after April 1?

Mr. BLOCH. That is my intent. Now I need to add one more thing to that. You should also know that I am somewhat concerned about 1986. We were talking about 1985 in the discussion we just had.

Senator DOMENICI. Yes, sir.

Mr. BLOCH. I am somewhat concerned about 1986. Let me tell you what my concern is. Maybe you can help me with it.

The budget request for 1986 that you have in front of you today assumes that we are going to get these additional funds over and above a level budget for 1985.

Senator DOMENICI. That is correct.

Mr. BLOCH. It is about $60-odd million. If we do not get these additional funds, I have to go back and reassess the priorities.

Senator DOMENICI. For the 1986 continuation?

Mr. BLOCH. For the 1986 continuation; like we have to with any other capital investment programs, like the Wisconsin program, like the Cornell upgrade program, which all are costly. They have to be reevaluated to see if we can carry them. It can very well be I will conclude that the VLBA is not affordable at that level.

Senator DOMENICI. I understand that.

Mr. BLOCH. I want to make that clear.

Senator DOMENICI. On the other hand, it is the prerogative of the Congress, and in particular the Appropriations Committee, to decide among the priorities. If, in fact, there is less funding overall than requested, and you decide that you are going to reconsider whether to fund the very long baseline array construction at $11.5 million, the funding level would ultimately be up to the Congress. You would have some input and tell us what you think.

Mr. BLOCH. Well, that is what I wanted to say.

Senator DOMENICI. Is that not correct?

Mr. BLOCH. You are absolutely correct. But I also ask and plead with you that we have some discussions on that particular subject so that we can be assured, you can be assured, and the Foundation and the community can be assured that we have a good balance between all of these various competing activities, that are all very important. But in a constrained budget era, one can't do everything.

NSF ACTIVITIES VITAL TO NATION'S FUTURE

Senator DOMENICI. I just want to close my side of the story with reference to Senator Proxmire's concerns about the increase in this budget. I don't think that at this point in my particular activities I take a back seat to anyone on restraining the cost of government. Frankly, I think you and the administration are to be commended in a tight budget year to ask for an increase for NSF.

I frankly see hardly any program in the United States that ought to be increased in a period of austerity if it isn't this one. The fruits of these programs are economic survival for the United States, production of scientists here in the United States that are competitive throughout the world, not sending all the great minds off to be medical doctors but, rather, encouraging some of them to be at NSF, in our great labs, and in engineering and science fields in the private sector.

If we can't provide some kind of stimulus for achievement and excellence, I don't see what good the Federal Government is doing in the whole field of education and economic development.

So I commend you for your work. You don't have to read between the lines. I support an increase in spite of cutting a lot of other programs.

Thank you, Mr. Chairman.

Mr. BLOCH. Thank you, Senator.

Senator GARN. Thank you, Senator.

Senator Lautenberg?

Senator LAUTENBERG. Thank you, Mr. Chairman.

BALANCE BETWEEN MILITARY AND CIVILIAN R&D

Briefly, Mr. Bloch, the National Science Foundation budget for fiscal year 1986 represents an increase over last year, but the overall trend in Government support of civilian research and development bothers me somewhat. Defense related R&D will total $43 billion, and that is up over 22 percent. Civilian R&D would total $16.7 billion, down from the previous year.

Now, 5 years ago, approximately, defense and nondefense R&D were roughly equal. Now defense R&D is approaching 70 percent of the total R&D expenditures.

Do you want to give me an opinion on what this trend means to our Nation in terms of our ability to maintain an industrial competitiveness and to maintain, as the Senator from New Mexico has mentioned, scientific excellence?

Mr. BLOCH. Obviously I am not an expert on all phases of R&D that the Federal Government supports and certainly not in the defense R&D aspects.

I support the President's budget as it is. It was arrived at through many negotiations with OMB. I thought, in light of our total situation, that NSF was well treated, and I stated that in the beginning. So that is point No. 1. I want to make it very clear that I support the President's budget totally.

Let me say one other thing. I have some experience in looking at the Department of Defense, especially the very high scale integrated circuit [VHSIC] project that has been ongoing for the last 3 or 4 years. I think it has some tremendous benefits to industry.

So there are things in the Federal budget or in the defense budget for R&D that I think will find their way into the industrial sector. Not everything will, because a lot of it is obviously very specialized, pinpointed, and so forth. But that is not true in all cases.

I also think there is more recognition today by the Department of Defense that they have a responsibility with regard to basic research, especially research in universities.

My understanding is that they are coming forward or have come forward in 1986 with an initiative that would deal directly with the universities in supporting fundamental research in universities, more so than in the past.

ADEQUACY OF NSF BUDGET TO MEET NEEDS

Senator LAUTENBERG. I appreciate the observations on the defense budget, and I know that is true, that there are things that spill over into the normal part of our existence that are of value. My focus really is on that R&D which is nondefense or civilian side stuff.

Even though you feel that you have been treated reasonably in terms of your mission as the Administrator here, is there enough for us to maintain the thing Senator Domenici raised: excellence in our science, excellence in the development of projects, programs, in view of the size of our economy, in view of the size of our GNP, in view of the strength of the competitive forces in other countries, in view of the focus of other countries on particular research and development that will ultimately turn into market share? You are familiar with these projects because at IBM you just couldn't sit in an ivory tower and plan. You had to have a mission.

Are we spending enough when we look at the total need, do you think, when we look at the sum of money being spent on civilian or nondefense R&D?

Mr. BLOCH. The answer to that specific question, and looking at the long picture, obviously is no, we are not spending enough. We have shortcomings.

By the way, let me say one thing. I think we have made some improvements in the last 3 or 4 years, significant improvements, but we have a long way to go. The instrumentation problem in the universities is a great problem. We have made progress in that, but we have a long way to go in that. Today, it is still a fact that industrial laboratories have better instrumentation, more modern instrumentation, than professors and investigators in universities have available. I think that is a shame. It should be the other way around.

It shouldn't be the other way around, either, by the way, but it should be level, essentially.

I think we are not attracting enough people to the science and engineering studies. We have to again put programs in place to help that.

But these are just individual programs and they are going to make a change and enhance a particular area, but it won't solve the total problem. So we have a long way to go.

Senator LAUTENBERG. Mr. Bloch, it is a pleasure to see you here. I look forward to the opportunity for us to chat more.

Thank you, Mr. Chairman. I appreciate your indulgence.

Senator GARN. Thank you, Senator.

You have been an impressive witness, and we thank you very much for your first appearance before the subcommittee.

Mr. BLOCH. Thank you, Mr. Chairman.

DIRECTOR'S STATEMENT COMMENDED

Senator LAUTENBERG. Mr. Chairman, as Mr. Bloch leaves the table, and please continue, I would have to tell you that you saw the imprint of his professional life in industry in terms of his statement. It was legible. It was logical. It was very well outlined. I found I could read it in 5 minutes, whereas other times these things take forever to get through.

Mr. BLOCH. It was even in English. [Laughter.]

Senator GARN. Thank you, Mr. Bloch.

SUBMITTED QUESTIONS

Mr. Bloch, we will have additional questions for your response in writing. I will have some more and some other members of the panel will as well.

[The following questions were not asked at the hearing but were submitted for response for the record:]

QUESTIONS SUBMITTED BY SENATOR GARN

SCIENCE AND ENGINEERING EDUCATION

One part of the NSF Budget which has received a great deal of attention has been your Science and Engineering Education program. Your statement, as well as that of Dr. Keyworth's, underline the need to attract, educate, and retain new American scientists and engineers.

It is a matter of great concern, therefore, that $31.5 million in this program is proposed for deferral into FY 1986. We appreciate the administrative difficulties of gearing up from the very low funding levels provided in the early 1980's, but it is clear that more than $82 million could be well utilized in this current fiscal year.

Question: What prompted this limit on your education program?

Answer: The major limiting factor at this point is the development of a comprehensive long range plan for building a coherent program that will effectively couple our relatively small but important effort to the massive $144.5 billion annual investment being made in precollege education by other Federal agencies, and by state, local and private sources. In 1985, Congress set aside $2.0 million for this purpose, and we will go out this Spring with the first round of proposals. This planning effort is crucial if we are to build a stable foundation for our future activities.

We have funded many excellent proposals. But I must point out that even a collection of excellent proposals does not necessarily make a cohesive program that is effectively coupled to the Nation's schools and teachers. This point was given special emphasis last year in our hearings before this Committee. Senator Garn stated, "We can spend ... or invest in the future. The difference between the past approach and the one needed for the future is, in my mind, a matter of developing specific program objectives and a strategy to manage the program and measure its success against these objectives." I believe that as the program objectives are more clearly defined through the planning process, more focussed proposals will be submitted and funded.

The precollege education area has grown from $1 million in FY 1983 to $50 million in FY 1985. This growth needs to be absorbed and consolidated and the wide fluctuations of the past need to be avoided.

But for now, we cannot prudently obligate in FY 1985 all of the funds available for the precollege programs. Thus, we are proposing to carry over a planned deferral of $31.5 million into FY 1986.

I want to emphasize, again, that education and human resources are among my chief concerns. I am committed to building a stable precollege science education program that provides leadership and serves as a catalyst for other Federal, state, and local programs.

My decision to carry forward funds that cannot be effectively obligated in 1985 does not jeopardize that commitment.

SCIENCE EDUCATION -- MANAGEMENT

Last year, Congress appropriated $2 million "for a contract to develop a science education plan and management structure for the Foundation." These funds were provided after an extensive series of discussions between the Subcommittee and the Foundation regarding the appropriate way NSF should manage its science education program.

Question: What is the status of this contract study?

Answer: A Commerce Business Daily announcement concerning the study was published on April 2, 1985. A Request for Proposals (RFP) is to be completed by the Science and Engineering Education Directorate and forwarded to the Division of Grants and Contracts by April 22. Responses to the RFP are due by June 17. All resulting awards are to be announced between September 15-30.

Question: When can the Subcommittee expect to review the preliminary results of this study?

Answer: The first series of studies will be contracted in September 1985. Preliminary results are expected in early summer 1986.

The need for such a management study was the result of discussions we had last year in which the Subcommittee was not convinced NSF has developed a strategic view towards the management of science education.

Question: Does the reorganization of the directorate reflect a change in approach by emphasizing the activity in a strategic way or do unsolicitated proposals still largely determine the overall direction of the program?

Answer: The term "unsolicited proposals" as usually applied, is inappropriate in the context of Science and Engineering Education (SEE) program operations. The current organization, formal program announcements and project selection procedures all result in a much more strategic approach than that used in the past. The new program announcements for precollege activities are quite precise in specifying program objectives and targets and in stating what NSF does and does not support. As our strategic planning activities continue, we will be issuing both supplements to our program announcement and new RFPs to continue our move toward a more proactive, strategic approach to NSF science education funding. Currently, each program within the SEE Directorate has clearly stated goals and objectives and employs project selection criteria that lead to NSF's support of projects that are directed explicitly toward achieving those objectives.

SCIENCE EDUCATION -- NSF ROLE

Question: How do the proposed science education activities within the NSF Budget make use of the Foundation's strengths in order to make a meaningful contribution in meeting the precollege science education needs of the Nation?

Answer: The National Science Foundation is in a unique position to make a valuable contribution to meeting the precollege science education needs of the Nation. Its tradition of excellence, its ties to both the college and university communities and to professional associations, and its support of cooperative research between universities and industry are all strengths in the support for science education.

The Foundation's science education programs are designed to leverage or stimulate efforts so that a relatively minimal financial investment can have long-lasting and pervasive effects on the Nation's education system. NSF's programs support the development of sets of materials, models, and exemplary programs that have the potential for widespread use throughout the Nation. Projects are selected for funding that reflect NSF's unique position to bring together practicing scientists with science educators.

Question: Could you discuss the change in focus that NSF's science education activities have undergone -- specifically at the precollege kindergarten through eighth grade level?

Answer: Although NSF-supported projects have focused on virtually all levels of education in the past, Science and Engineering Education (SEE) activities are now emphasizing the critical early precollege years. All of the recent education commissions and reports -- particularly the National Science Board Commission -- have focused on the importance of early, high quality exposure to mathematics and science in determining not only adult career choices, but also lifelong attitudes toward and aptitude for mathematics and science. These analyses have also pointed out many serious problems with existing elementary and middle school mathematics and science education programs. For example, elementary school teachers receive virtually no formal training in mathematics or science education; and the middle school science curriculum is in serious need of both substantive and pedagogical attention. Through the vehicles of public pronouncement and formal program announcements and solicitations, SEE is emphasizing work on these critical middle and elementary school years. To date, over 50% of the projects supported have focused on these years; we expect that trend to continue.

Question: What agreements -- both formal as well as informal -- has NSF entered into with the Department of Education to coordinate the activities of both agencies?

Answer: NSF has both formal and informal collaborative arrangements with the Department of Education (DoEd). We have jointly supported a number of projects. For example, NSF and DoEd have collaborated in supporting "3-2-1- Contact" and a new Children's Television Workshop series in mathematics. In this case, NSF was the lead agency with DoEd cooperating in the review and support of the project. In another case, DoEd was the lead agency for the support of "Voyage of the Mimi," a television series teaching about the scientific method for children in grades 4-8 that not only involves production of a television series for public television stations, but includes materials for students and teachers to use in the classroom. In this case, the DoEd coordinated the review and provided the majority of the funding; NSF is involved in overseeing the scientific content and provides partial support for development of materials for classroom use by students and teachers. In addition to these formal collaborations, NSF and DoEd staff meet regularly to review each others' programs and explore possibilities for collaboration. This occurs both with National Institutes of Education (NIE) and with other parts of DoEd. These kinds of discussions occur at least weekly.

NSF and DoEd are working together informally to alert state and local educational agencies that will receive DoEd funds through Title II of P.L. 98-377 to the opportunities they have to support teachers as participants in NSF-funded, merit-based teacher enhancement projects or to support the projects themselves as partners. We have given copresentations on these topics and DoEd will distribute to state and local educational agencies the "Directory of NSF-Sponsored Teacher Enhancements Projects" for 1985-1986.

NSB COMMITTEE ON EXCELLENCE

The recent report from the Board's Committee on Excellence on the role of politics in research funding decisions, as you might imagine, generated some interest in Congress. This Subcommittee has been a strong supporter of the merit-based review process and has consistently resisted earmarking specific scientific research projects. The report discusses some of the underlying reasons for institutions attempting to bypass the peer review process.

Question: Would you highlight some of the underlying reasons and what role should the Foundation play in addressing these problems?

Answer: Some of the reasons offered by institutions attempting to bypass the peer review process in order to receive support for major facilities include:

- need for facilities to house new research initiatives;
- deterioration and obsolescence of existing facilities;
- increased funding for science and engineering research without a balanced consideration of the resulting demand for improved and additional facilities; and
- more rapid increase in the cost of facilities and equipment as compared to salaries for researchers.

With regard to the role that the Foundation might play in addressing the problems outlined above, two broad areas have been defined:

- characterization of the nature of the problem
- development of appropriate and feasible solutions.

The Foundation obviously cannot attempt to address the problems alone. We can, however, play a leadership role, working with universities, states, the private sector, other Federal agencies and organizations such as the Office of Science and Technology Policy, the White House Science Council, and the National Academies of Sciences and Engineering.

Question: What progress has been made in implementing the recommendations of the National Science Board's report with respect to the evaluation of the merit review process and a conference on academic research facilities?

Answer: I have, in consultation with the National Science Board, established a committee with membership external to the Foundation to take a look over the next several months at the way the peer review system at NSF is working. Dr. Norman Hackerman, former National Science Board Chairman has agreed to head this important group. Some of the questions they will explore are: review methods at other science support agencies; differences between NSF directorates with regard to peer review; peer review as applied to diverse types of activities (international, facilities, targeted programs, etc.); fairness of the peer review system for specific groups of institutions, individuals, or other constituencies; strengths and limitations of present procedures; and options for change.

Planning for a conference on academic research facilities has begun under the direction of the Deputy Director-designate. A tentative date in mid-July has been selected.

BUDGET FREEZE

As you know, Congress is considering a budget "freeze" as a strategy to reduce the Federal Deficit.

Question: If the NSF Budget were held to your current FY 1985 level, what measures or strategies would you recommend?

Answer: A budget freeze at the FY 1985 level would have serious consequences for NSF. It would involve about a $57 million reduction from our FY 1986 program plan and would have ramifications across most of the Foundation's programs.

If faced with such a freeze situation, the general strategy would be to protect scientist (people) support to the maximum extent possible and to seek reductions in instrumentation and facilities first. This would mean, for example, that our large capital improvement projects such as those at Cornell (CESR), Wisconsin (Aladdin), and the VLBA would have to be examined for further stretchout or deferral. Instrumentation increases would need to be reduced across the full range of scientific disciplines which would slow the gains we have been making in this area over the last three years.

Engineering Research Centers would probably need to be reduced, which would result in fewer new centers in FY 1986, and in addition, the buildup rate of the FY 1985 centers would have to be slowed. A similar determination would have to be made with regard to the supercomputer initiative. No new centers could be considered in FY 1986. In project support, increments to several important initiatives would have to be reduced by about 50%, e.g., advanced materials, biotechnology, continental lithosphere, mathematics personnel, and social and economic sciences. In the Antarctic program plans for renovation and replacement of buildings would also be candidates for reduction.

Reductions on this scale will seriously slow the momentum that has been built up in previous years in areas important to scientific progress and economic security. If we don't invest in graduate students, postdoctorates, and faculty researchers today, the talent and ideas needed for the future will not be available when the Nation needs them.

JOB PLACEMENTS OF SCIENTISTS AND ENGINEERS

An issue we raised in last year's hearing was the job market for scientists and engineers. I think this is a critical issue because while, as a government, we may attempt to influence the quantity and quality of the talent yielded by our educational system, a very fundamental factor in this equation is how our society values the particular skills and abilities we seek to enhance. The question of whether there will be jobs for the scientists and engineers that we can produce, in large measure, determines the number of students pursuing a science and engineering research curriculum which, in turn, determines the allocation of resources within the academic community.

Question: First of all, do you agree with this assessment?

Answer: Yes, we agree. Our projections of supply and demand indicate that as the demand for scientists and engineers grows, so does the supply, although often the growth is not sufficient to meet the demand, and at times lags behind the need.

Question: What is NSF engaged in to assess the job market for science and engineering graduates?

Answer: The Foundation engages in a number of activities to monitor the job market for scientists and engineers. These activities include projection studies of demand and supply conditions across science and engineering fields; employer surveys that describe past employment trends and indicate future demand within major sectors of the economy; and "quick response" surveys that provide timely information on the needs and perceived supply of science and engineering personnel. In addition, the Foundation assembles information from secondary data sources on general employment conditions that define the labor market environment in which new graduates must compete. Such data include: occupational projection and employment data obtained from the Bureau of Labor Statistics; data on the number of jobs and wages offered to new science and engineering graduates obtained from the College Placement Council; the high-technology recruitment index developed by Deutsch, Shea and Evans, etc.

The National Science Foundation conducts two surveys that provide information on the recent job market performance of science and engineering graduates. The Survey of Recent Science and Engineering Graduates, provides information biennially on the characteristics of new B.A.- and M.A.-degree recipients; the Survey of Doctorate Recipients provides similar information for doctoral degree recipients. These surveys report a variety of employment-related characteristics such as labor force participation, unemployment experience, utilization in science and engineering or related jobs, sector of employment, etc. Recent surveys of new entrants have indicated that engineering and computer science graduates have the lowest unemployment rates and highest skill utilization rates, although a significant number of computer personnel use these skills in non-science and -engineering activities. Doctorate surveys show significant sectoral shifts away from academia toward industry, particularly for engineering and the physical science graduates.

The Foundation also maintains an Industry Quick Response Panel which has been used to monitor employer perceptions of personnel shortages. The Panel is made up of over 300 medium- and large-size firms which account for approximately 13 percent of industrial employment in science, engineering, and technician occupations. After a period of slack due to the 1981-1982 recession, the 1984 survey has shown industrial shortages to be reappearing in some engineering fields. The survey has consistently shown that problems for recruiting experienced personnel are greater than for new graduates except in electronics engineering.

Question: Beyond the direct support NSF puts into support of research, what activities are you engaged in to stimulate the expansion, by industry, of research and development employment opportunities?

Answer: NSF has no program with the specific purpose of expanding employment opportunities for scientists and engineers in industry. However, we believe that the expansion of knowledge resulting from NSF-supported research will, in the long run, have that result. One activity that has a more immediate effect on job opportunities in research and development is the Small Business Innovation Research (SBIR) program. This program assists small science and technology-based firms to carry out research in high risk areas, with encouragement for private-sector involvement in converting the research results to commercial applications. Small high technology firms are major contributors to employment growth. The FY 1986 budget allocates $13.3 million to the SBIR program.

Other special NSF programs that help to stimulate industrial research expansion, and thus, indirectly affect employment opportunities are: the Industry/University Cooperative Research Centers, which seek to foster industry/university interactions by supporting basic and applied research at university centers in high technology fields; and the Experimental Program to Stimulate Competitive Research (EPSCOR), which provides incentives for academic and industrial leaders within states that are relatively less successful in competing for research funds to establish research improvement plans to improve local research capacity.

VERY LONG BASELINE ARRAY (VLBA)

The budget request proposes to stretch out the schedule for the VLBA by requesting $11.5 million.

Question: Does the VLBA still remain an NSF priority in ground-based astronomy?

Answer: Yes. The VLBA is unique in its productivity compared with the existing U.S. ad-hoc very long baseline interferometry network and with all existing and planned systems elsewhere. It continues to have the strong support of the astronomical community and remains as the highest priority major new program for ground-based astronomy. Our understanding of the universe will increase significantly because of the VLBA.

Question: When do you expect to obligate the FY 1985 construction funds for the VLBA?

Answer: At the request of the House Appropriations Committee we now expect to begin to obligate the FY 1985 construction funds on May 15, 1985. The National Radio Astronomy Observatory (NRAO) is prepared to start construction at that time.

I understand that NSF is still reviewing possible options to stretch out the construction phase of the VLBA.

Question: Please describe these alternatives, including the ramifications that each would have on the utility of the system in yielding useful science during the construction phase.

Answer: The optimum construction schedule, as originally presented by the National Radio Astronomy Observatory (NRAO), was a 3-year plan. In developing the FY 1985 request, a 4-year plan with approximately level funding of $15 million (1985 dollars) was adopted. Congressional action delayed the start of construction to April 1, 1985, and reduced FY 1985 funding from the requested $15.0 million to $9.0 million. The budget request of $11.5 million for FY 1986 stretches the construction funding period to 5 years, delaying completion by 2 years and increasing total project cost, while nevertheless adhering to the terms of the negotiated fixed-price antenna contract. The total cost and completion date in the FY 1986 budget request rests on planned future-year funding ("current plan") of $17.7 million (FY 1987), $18.0 million (FY 1988), and $14.2 million (FY 1989). Actual funding in future years obviously is subject to revision according to the annual budget and appropriations process.

The Foundation is indeed reviewing alternative construction schedules, analyzing the impact of the stretch-out at the $11.5 million request level in FY 1986. While the antenna subcontracts can be satisfied as negotiated, the development and procurement of other vital subcomponents, such as electronics, data acquisition, recording and correlating systems, must be delayed. Minimizing the negative impact of these delays is a primary objective of the current reviews. From the viewpoint of optimizing the scientific output as well as the total project costs, we have concluded that retaining the antenna procurements as pacing items is desirable.

The Foundation has examined budget levels below and above those contained in the FY 1986 request. NRAO has prepared alternative construction schedules ranging from the "current plan" detailed above to $9.0 million (1985 dollars) annually to project completion. This range of analyzed scenarios spans project costs from $70.4 million to $86.5 million, and project completion dates from 1990 to 1993.

The main scientific impact of the VLBA will occur when all antennas and other system components are operational. Analysis of alternative scenarios has persuaded NSF that optimizing partial operations, for instance, by speeding up the procurement of correlating and post-processing equipment at the expense of antenna procurements would be less advantageous than the current plan.

The Foundation has given high priority to the VLBA and intends to proceed with it as expeditiously as possible.

Question: What impact will a stretch out have on the viability of the existing contract proposal for construction?

Answer: The principal existing contracts are the two subcontracts for procurement and erection of the 10 antennas. The FY 1986 funding level of $11.5 million is sufficient to permit NRAO to honor the terms of the negotiated antenna subcontracts, so that delays will affect other system components of the VLBA.

SACRAMENTO PEAK OBSERVATORY

I understand NSF may receive a recommendation from Association of Universities for Research in Astronomy, Inc. (AURA) to close the Sacramento Peak Observatory (SPO) in New Mexico.

Question: What are the procedural steps that NSF will employ to consider such a recommendation?

Answer: Following actions by the AURA Board, AURA must forward to NSF its request for proposed changes to the FY 1985 program already approved by the Foundation for the National Optical Astronomy Observatory (NOAO).

The request from AURA will be considered by the NSF's Advisory Committee for Astronomical Sciences (ACAST) at its meeting May 6-7, 1985. This meeting will be held in Tucson, Arizona to facilitate in-depth discussion of this topic, which will be a major item on the agenda for the meeting. The ACAST will be supplemented with experts from the solar physics community for this discussion.

The Foundation may also solicit written reviews of the AURA request from members of the affected communities.

The Foundation has notified the Air Force Office of Scientific Research, which provides some funds for support of SPO, that we expect changes to be proposed, which may include closing of SPO. Dr. Jefferies, Director of the National Optical Astronomy Observatories (NOAO), has notified the Air Force Geophysics Laboratory, which maintains a contingent of scientists at SPO, of his intention to recommend closure of SPO. The Astrophysics Division of the National Aeronautics and Space Administration (NASA) has also been informed of Dr. Jefferies' intentions.

NASA and the USAF will be requested to review the recommendations submitted to the Foundation. Appropriate officials of these agencies will be invited to provide their views and comments in time for consideration by the ACAST at their May meeting.

Question: To what extent will the astronomy community and the National Science Board be consulted regarding this recommendation?

Answer: Advice from the ACAST meeting together with other opinions, solicited and unsolicited, from the astronomical community will be considered in arriving at the Foundation's response to AURA's proposal. The Foundation's response will be reviewed by an appropriate committee of the National Science Board.

Question: What information do you have on the status of this proposal?

Answer: Dr. Jefferies, Director of the National Optical Astronomy Observatories (NOAO), presented his recommendations to the AURA Board on March 28, 1985. We are awaiting the formal submission of the conclusions to NSF.

Question: What implications will such an action have on your budget?

Answer: The purpose of the proposed changes to be recommended by AURA is to allow NOAO to bring their operations into line with present and projected budget levels while maintaining the capability to develop new research programs in promising new areas.

Question: To what extent is the Air Force involved with the maintenance and support of Sac Peak?

Answer: The USAF partially supports the operations and maintenance activities at SPO. The level of this support in FY 1985 is $435,000. The USAF also maintains a contingent of scientists and technicians at SPO. At present there are eight people supported directly by the USAF at SPO.

Question: Does there exist some formal agreement between NSF and the Air Force regarding Sac Peak?

Answer: There is a Memorandum of Understanding between the Air Force and NSF dealing with support of research activities at SPO. The present agreement expires on September 30, 1985.

Question: Does the potential closing of Sac Peak represent a violation of that agreement?

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Answer: The USAF partially supports the operations and maintenance activities at SPO. The level of this support in FY 1985 is $435,000. The USAF also maintains a contingent of scientists and technicians at SPO. At present there are eight people supported directly by the USAF at SPO.

Question: Does there exist some formal agreement between NSF and the Air Force regarding Sac Peak?

Answer: There is a Memorandum of Understanding between the Air Force and NSF dealing with support of research activities at SPO. The present agreement expires on September 30, 1985.

Question: Does the potential closing of Sac Peak represent a violation of that agreement?

Answer: No. The agreement contains the provision that it may terminated by either party.

Question: If Sac Peak is closed, what will become of the research, the people, the instrumentation and the facility in general?

Answer: If a recommendation to close Sac Peak were to be forwarded, it would have to provide detailed answers to these questions for review by the NSF. A recommendation to severely curtail operations at Sac Peak would also be subject to review as described above. Issues such as these will be examined in the course of developing the NSF response to whatever recommendation is put forth by AURA.

KECK OBSERVATORY

Recently it was announced that the Keck Foundation would fund a $70 million 10 meter multimirror telescope in Hawaii. Most intriguing about this telescope is the statement by Dr. Jesse L. Greenstein that this telescope "with its huge light-collecting area, will be able to conduct observations far beyond the reach of the Space Telescope." I might add that the Space Telescope is expected to cost 17 times the price of the Keck proposal. An article in the New York Times (February 12) goes on to describe yet another even larger "New Technology National Telescope" which will have the power of a 15 meter telescope.

Question: Can you briefly sort out for us the specific advantages the Space Telescope will have over these more powerful ground based telescopes?

Answer: A full comparison of the capabilities of large ground-based telescopes, e.g., the 10-meter Keck Telescope and the Hubble Space Telescope (HST), is a complex issue. Whether one will perform better than the other depends on the type of observation, the observing conditions, and the wavelength region and environment of the object in the sky (e.g., a crowded field). In general, the HST enjoys three great advantages over any ground-based telescope:

- freedom from atmospheric absorption, providing access to the ultraviolet region of the spectrum;
- spatial resolution limited only by the optics of the telescope and not by the atmosphere; and
- reduced background light, particularly in the near infrared region of the spectrum.

With these advantages, the HST will be used to attack problems that one cannot attack using a ground-based instrument. A few examples are:

- The HST will provide the largest aperture ever available in the ultraviolet to study important diagnostic spectral lines and to observe hot objects and energetic processes in the Universe.

- The HST will provide unmatched capability to detect extremely faint point sources. Some of these will be so distant that the light reaching the HST will have been emitted soon after the beginning of the Universe and will contain important clues about its early history.

- The HST will provide information about the structure of galaxies, quasars, processes in the atmospheres of planets, and other phenomena that have been hidden by the blurring effect of the Earth's atmosphere.

The Keck Telescope will be an excellent complement to the capabilities of the HST. Its light-collecting area is 16 times that of the HST. It will be used to tackle problems whose solutions require gathering more photons than a telescope the size of the HST can provide but that do not require access to the ultraviolet or the superb angular resolution of the HST. Some examples are:

- Spectroscopic applications where spatial resolution is not important, such as the collection of redshifts for large numbers of faint and distant quasars.

- Imaging of faint, extended sources, such as the outer regions of galaxies and supernova remnants.

- Spectroscopy and imaging in the longer wavelength infrared region where detector noise dominates the sky background. The blurring effect of the atmosphere in the longer-wavelength infrared region is small enough that image sizes are limited only by the telescope optics. Such diffraction limited images will be crucial in understanding the birth and early evolution of stars like our Sun.

In these areas, the 10-meter telescope will perform observations beyond the capabilities of the HST. In the areas in which the HST was designed to excel, it will outperform any existing or planned ground-based optical telescope by orders of magnitude. The instruments are designed not to compete but to provide astronomers with complementary information for a broad range of important astrophysical problems.

Question: What implications do these telescopes have on National Science Foundation (NSF) funding, both for operation of existing telescopes, as well as for development, acquisition and operation of these new proposals?

Answer: The 10-meter Keck Telescope is a joint project between the California Institute of Technology and the University of California. Current plans do not call for a proposal to NSF to fund the construction or operation of this telescope. The telescope would be used primarily by astronomers from California. After the telescope is in operation, occasional proposals to NSF for auxiliary instrumentation and scientific research using the telescope are likely and would be considered under the normal peer-review process.

A technology development program designed to solidify the basics of large-mirror fabrication techniques, mirror-support technology, site-evaluation techniques, and other factors that bear directly on the cost and performance of large telescopes is currently being funded by NSF. The results of this program will be of wide benefit, improving the performance of existing telescopes as well as influencing the design and cost of telescopes with apertures of 3 meters and larger in various stages of planning by several universities and consortia. In one of these efforts, members of the astronomical community are studying a concept which they refer to as the "National New Technology Telescope," using 4 individual 7.5-meter mirrors on a single mount to obtain the power of a single telescope 15 meters in diameter. An instrument of this aperture was recommended by the National Academy of Sciences report, "Astronomy and Astrophysics for the 1980's." Should a proposal for such an instrument be presented to NSF, it would be considered on its scientific merits, its priority in relation to other competing proposals, and the availability of funds.

ETHICS AND VALUES IN SCIENCE AND TECHNOLOGY (EVIST)

One small program proposed for termination is the $1 million EVIST program. This proposal has generated a good deal of concern since EVIST is virtually the only ongoing Federal effort to address a growing multiplicity of ethical issues associated with advances in science and technology.

It has been suggested that one reason it was proposed for termination was because it doesn't fit well with the "hard" science activities of STIA.

Question: If Congress were to restore this program, in which directorate would you recommend it be placed?

Answer: Our current plans are to administer the ethics and values activities of the Foundation in a distributed mode; that is, all directorates would have responsibilities for supporting projects in ethics and values in science and technology. A target funding level would be set for the Foundation as a whole and special tracking mechanisms would be put in place. There would be a central coordinator for the effort whose responsibility it would be to provide advice on locating reviewers, track proposals that are submitted, monitor funding levels, and provide information to requests from internal and external sources. This approach is similar to that followed for our Research in Undergraduate Institutions program activity and the Presidential Young Investigators program. An organizational location for this coordinator has not been established yet.

ENGINEERING RESEARCH CENTERS

Question: What is the status of the Engineering Research Centers program?

Answer: On October 1, 1984, the program received 142 proposals from 106 different engineering schools, requesting $2 billion for five years. A preliminary panel reviewed the proposals and categorized 40 as "highly recommended." A higher level "ERC Panel" reviewed those recommendations and site visited 14 proposed centers. The ERC panel then made recommendations to the Foundation and six proposals were approved for support by the National Science Board. The centers to be established this year are:

- ° University of California, Santa Barbara: ERC for Robotic Systems in Microelectronics, Susan Hackwood, Center Director

- ° Columbia University: ERC for Telecommunications, Mischa Schwartz, Center Director

- ° University of Delaware: ERC for Composites Manufacturing Science and Engineering, Byron R. Pipes, Center Director (Rutgers University is affiliated with this ERC)

- ° Massachusetts Institute of Technology: ERC for Biotechnology Process Engineering, Daniel I. C. Wang, Center Director

- ° University of Maryland: ERC for Systems Research, John S. Baras, Center Director (Harvard University is affiliated with this ERC)

- ° Purdue University: ERC for Intelligent Manufacturing Systems, King-Sun Fu, Center Director

Question: In addition to the centers you will start in FY 1985, how many new centers are proposed for FY 1986?

Answer: The budget request for FY 1986 is $25 million. Granting of this request will permit continuation of the FY 1985 centers and establishment of 6-8 new centers during FY 1986.

Question: How many centers are called for in the long-term plans for the program?

Answer: The National Academy of Engineering report "Guidelines for Engineering Research Centers" concluded "...that a target of 25 centers should be established for the overall program and that the commitment and funding level for each center must be adequate to affect directly at least 10 percent of all of the graduate engineering students in the Centers' home institutions." The final number of centers will depend on a number of factors including: availability of funds; the balance between funds for individual engineering research projects and Engineering Research Centers; the quality of proposals received; and the perceived need for the research foci of the centers.

Question: How do you propose to evaluate the progress of these centers?

Answer: The FY 1985 ERC announcement states that three years after the centers are established they will be evaluated by the ERC Panel to determine if the Center is meeting the goals and objectives proposed including the quality of the research and the extent of industrial participation. This evaluation will be used by NSF to determine whether to continue support or provide decreased funding to terminate the center at the end of the grant.

Before the formal evaluation of the centers, NSF will systematically collect "indicators" of progress for each center. These indicators will be developed in cooperation with the Center Directors.

Question: Please provide, for the record, a listing of the centers currently funded indicating the levels of private and other non-Federal support for each.

Answer: The support listed below (either in actual dollars or in-kind support) for the centers are considered to be firm at this time. All of the centers are actively engaged in securing additional industrial support this year. NSF will be encouraging gaining of industrial support in three categories: industrial personnel for participation in the research and educational activities of the center; specialized equipment from industry, or use of specialized equipment at the industrial site; and funds for support of Center activity.

University of California, Santa Barbara:

The University has pledged $300,000 for 1984-85, $400,000 for 1985-86, and $300,000 for 1986-87.

Columbia University:

Four companies have pledged $200,000 each year for three years.

University of Delaware:

The University has pledged $5.5 million over five years for facilities.

New industrial commitments of $400,000 have been received. Commitments to the prior Center for Composite Materials, subsumed by the ERC for Composites Manufacturing Science and Engineering, total $1,050,000 from 30 industrial sponsors. The Rutgers affiliate program has 24 firms contributing a total of $800,000 each year.

Massachusetts Institute of Technology

The University has committed 7,000 square feet of space to the ERC.

University of Maryland:

The University has pledged $1.0 million for five years for administrative support; $2.0 million for space (10,000 square feet); 2 full-time faculty positions.

Three firms have made commitments for a total of $660,000 for the first year of the ERC's operation and 9 other firms will become new industrial affiliates. The level of support from the latter is unknown at this time.

Purdue University:

The University has pledged 26,000 square feet for a facility and $50,000 for an international travel fund.

Six industrial partners will contribute $300,000 each per year and one will contribute $330,000 per year plus a one time gift of $500,000 for a computer.

FEDERAL PARTICIPATION

The U.S. Department of Agriculture (USDA) has been conducting a competitive grants basic research program modeled on the NSF peer review system.

Unlike NSF, however, USDA permits full participation by Federal researchers in their competitive grants program.

Question: In light of your statement that NSF must seek the best research possible, why does your agency seemingly preclude Federal laboratories from obtaining grants?

Answer: The Foundation supports research mainly at colleges and universities because there is exceptional research talent there and, importantly, research support at academic institutions produces both research results and trained personnel needed by government, industry and academia.

There are some very specific exceptions to this practice:

- Special Projects -- In exceptional circumstances in which the Federally-Funded Research & Development Centers (FFRDC's) or other Federal agencies can make a unique contribution, their support will be funded by NSF. In particular, when contemplating establishment of new multi-user facilities, NSF considers using, expanding, or upgrading existing facilities of other agencies.

- National and International Programs--NSF may fund research and logistic support activities of other government and agencies or FFRDC's directed to the goals of special national and international research programs for which NSF bears special responsibility. Examples are the U.S. Antarctic Research Program and cooperative science and technology programs with other countries.

- International Travel Awards--Staff scientists of other Federal agencies may receive NSF international travel awards to ensure appropriate scientific representation or availability of a particular expertise at an international meeting or conference.

- Military Service Academies--Research and science and engineering education proposals submitted on behalf of faculty members at U.S. military academies will be accepted and subjected to competitive review and evaluation in the same way as proposals from other academic institutions. However, the NSF will not ordinarily make an award to a service academy for major capital facilities, and will make no award for routine functions of a service academy that normally would be funded from its own appropriations.

BIOTECHNOLOGY

NSF's initiative in biotechnology reaches almost $80.0 million in FY 1986.

Question: Which areas within this broad field will receive emphasis if the budget request is approved?

Answer: Within the broad area identified as biotechnology the Foundation plans to concentrate on those research areas of a very fundamental and long term nature. Examples of research topics in this category include the physical biochemistry and computer modeling of enzymes and membrane proteins with the goal of determining precise structure-function relationships. These structural studies will allow the eventual directed modification of enzyme or protein active sites through genetic manipulation. Another high priority is the search for new mechanisms for the transfer of genetic material into all types of plant cells. The associated techniques of plant cell tissue culture and microinjection are also areas of special emphasis. The Foundation also intends to play an active role in the study of new techniques for scale-up technology in fermentation and product separation. An important portion of the biotechnology effort involves the multidisciplinary training of younger scientists through the award of postdoctoral fellowships in plant cell molecular biology; microbial ecology with an emphasis on molecular techniques; or the broader biological training of engineers.

USDA is emphasizing basic research in biotechnology issues.

Question: How are the initiatives of NSF being coordinated with USDA?

Answer: Many of the most exciting research topics in the biological sciences funded by NSF involve plant cell biology. NSF has been a leader in the stimulation of a broad area of the molecular biology and genetics of plants and plant cells. This research program has been carefully coordinated with USDA. NSF and USDA have separate, but complementary research missions. The emphasis of USDA is to support basic and applied research related to food and agriculture while the NSF supports the most fundamental research, some of which has significance to agricultural science.

USDA research is supported by three services within the USDA, Agricultural Research Service (ARS), Cooperative States Research Service (CSRS) and Forest Service (FS). ARS supports work in the USDA system of national laboratories while NSF does not generally support work in other Federal agencies. NSF supported scientists collaborate with these national laboratories and NSF staff are responsible for review of the work and make site visits when possible.

CSRS provides formula funding for land grant institutions and runs the Competitive Grants Research Office (CGRO). NSF staff and USDA staff in CSRS and CGRO routinely exchange information on supported proposals as well as proposals which are undergoing dual review. Generally CSRS supports work of a more applied nature which does not overlap with NSF programs. Coordination with CGRO involves the active input of NSF through membership on the Competitive Research Grants Office Policy Advisory Committee.

The Forest Service supports primarily Federal scientists who work in National Forests. NSF supported scientists have had excellent cooperation with the FS especially in studies of long term forest ecology.

Other coordination has been achieved through the Interagency Committee on Plant Sciences which was organized by NSF and includes members from several agencies, including USDA. This committee meets 8-10 times a year to discuss scientific and policy issues. NSF is also represented on the Agricultural Recombinant DNA Advisory Committee as well as the CRGO Policy Advisory Committee.

POLICY RESEARCH AND ANALYSIS (STIA)

A major reduction is proposed for policy research and analysis -- a cut of $2.7 million or nearly a 60% reduction for this activity.

Question: Please explain why you feel these activities should be reduced so dramatically.

Answer: In a difficult year, I took a careful look at many activities, and in particular those that are on the periphery of basic research. There is no question that there is a need for in-depth policy research and analysis (PRA). I took a very careful look at the analysis and reports generated by PRA. Some of the issues dealt with were relevant, and the resulting reports and papers were very useful and well-prepared; other contributions were of principal interest to other agencies. I felt that by eliminating the non-NSF efforts, and placing an emphasis and giving priority to the important issues, we could make some reductions in PRA and still produce timely and effective analyses on relevant issues.

Since, in principle, the thrust of this activity is to analyze and assess multi-agency research and technology issues, I would expect that OSTP would be concerned with this drop in resources.

Question: What role did that Agency have in this decision?

Answer: The decision was mine. However, I discussed my decision with both OSTP and OMB.

PROGRAM DEVELOPMENT AND MANAGEMENT (PD&M)

The Senate Budget Committee has recommended against the proposed 5% pay reduction. If this recommendation holds up, some restoration of the Program Development and Management activity will be in order. The NSF's Budget has fared well in the past few years, but staffing levels have continued to decline.

Question: Are productivity improvements in equipment and other areas allowing this to happen?

Answer: Yes, the Foundation has implemented or is in the process of implementing several productivity improvements that will permit effective execution of increased budgets at a lower staffing level. These improvements can be grouped into the following categories; more efficient equipment, expanded usage of personal computers and data processing equipment, streamlining work flow procedures, and more efficient assignment and utilization of available personnel. Included in the first category, more efficient equipment, are such in place improvements as automated filing systems, word processors and electronic mail systems. The second category, expanded usage of personal computers and data processing equipment, includes conversion of the Foundation's ADP systems from a Honeywell mainframe of three Hewlett-Packard minicomputers which, along with improved software, permit faster processing and more "user friendly" operation. During FY 1984 and continuing into FY 1985, the Foundation has begun implementing a phased-in plan for having personal computers available to all staff who have a recognized need for them and can utilize them in performing their duties. When the plan is fully operational we expect this to be the most important single factor in the Foundation's ability to meet expanded programmatic responsibilities with less staff.

Question: Can you tell the Subcommittee some of your ideas on how staff productivity can be improved?

Answer: The Foundation has considered the problem of improving staff productivity for some time now and has identified a number of areas where realistic changes will produce significant improvements. Chief among these is providing the employee with the appropriate work environment to do his job in the most effective manner. An example of this is providing the employees with workstations having the specific data processing and communication links necessary to do a particular job. The various mixes of equipment, depending on the function of the employee, can include personal computers with or without word processing capabilities, printers, and direct on-line access to the central minicomputers. Critical to taking full advantage of this workstation concept is providing the most appropriate software enabling the employee to utilize this equipment. The Foundation has tested a number of standard software packages and has selected packages most appropriate to our needs.

As a result of wide availability of personal computers and staff trained in their use, a number of manual operations have been automated. For instance, input to the Foundation's annual budget submission to the Congress is now almost entirely done through use of personal computers. As a result, significant manpower savings have been achieved.

Similar savings have resulted in using personal computers in the grants processing procedures, correspondence with grantees and in other processes which are heavily labor intensive.

In another area, the Foundation is experimenting with various flexible assignments of the work force. For instances, secretaries who formally were assigned to one or two program managers are now available on an as needed basis to a much larger group of program officials. Flexible work schedules and staggered working hours have also provided longer hours of staff coverage with the same or lesser number of employees.

The Foundation has many highly paper intensive operations which are being examined and, where possible, being converted to systems of electronic information and record keeping. We will start to experiment with an automated electronic proposal system to reduce the excessive paperflow that exists today. This is part of our major overall effort of paperwork reduction.

The Foundation is continuing to study the problem of employee productivity improvement and as proven methods are identified will apply the methods on an agency-wide basis.

Question: Are travel funds adequate to provide appropriate oversight of research projects being supported to assure good public accountability?

Answer: The FY 1986 estimate for all travel of $3 million is approximately the same level as FY 1984 and FY 1985 and reflects the Administration's policies on holding down agency administrative costs. While the Foundation is in agreement with these policies, adequate implementation of increases in programs approved by the Congress, such as an expanded Science and Engineering Education program, Engineering Research Centers and Advanced Scientific Computing, without corresponding increases for items such as travel must, by necessity, mean the reduction of travel funds for other programs. The full amount of the travel request in FY 1986 will meet minimum requirements.

Question: What other high priority items in this activity should this Subcommittee be aware of?

Answer: As mentioned at the beginning of these questions, the Foundation's estimates for personnel compensation and benefits are based on the Administration's assumption of a 5% pay cut in salary rates. The FY 1986 FTE ceiling is 1,174 and if it is necessary to absorb the 5% deficit, assuming no change in salary rates, approximately 59 authorized FTE's would not be funded, causing a serious staffing problem. Since the requested amounts for most other PD&M budget categories are at or below FY 1985 levels, there is little room for further reductions here. About the only major discretionary area is the proposed funding for new productivity improvement tools and the decision support system that the Foundation has been developing for several years. However, those activities are so important to the future of the Foundation's activities, they must be given the highest priority even in a severly constrained budget environment.

U.S. ANTARCTIC OPERATIONS SUPPORT

Included in your request is $5 million for the second increment of a Service-Life Extention Program (SLEP) for the two oldest LC-130 aircraft. Congress deleted this amount in FY 1985 because of contractual problems with the Navy.

Question: Please describe the nature of this upgrade program and the total cost associated with the two aircraft in question as well as expected future year requirements for the other LC-130's in your inventory.

Answer: The LC-130 upgrade program involves the replacement and/or upgrade of selected instrumentation, electronics, and structural components of the two "F" model LC-130s, the oldest of the big ski equipped transports. One has already received the instrumentation/electronics system upgrade. FY 1984 funds are being used for long lead time procurement for this work on the other aircraft. FY 1986 funding will continue with structural component procurement. Installation of these upgrades will occur concurrently with, but over and above, the scheduled annual depot level maintenance over the next three years.

The total cost and funding schedule is:

FY 1984	$ 5,000,000
FY 1986	5,000,000
FY 1987	4,000,000
	$14,000,000

Completion of this "over and above" maintenance program will improve the gross weight capability and will upgrade overall reliability to enable planned operation of 30,000 hours service life.

The U.S. Antarctic Program employs a total of seven NSF owned ski C-130 aircraft including five of the newer "R" models. The typical operating schedule is for six to be deployed to Antarctica each year during the September to March operating season, while one remains in major depot level maintenance. Due to the extremes of the operating environment the aircraft are scheduled for depot level maintenance every year, normally during the March through August period. Sufficient aircraft must also be available during this "off season" period each year to enable essential air crew training.

Future year requirements for all inventory LC-130 aircraft are now being studied. As requested by NSF, the Naval Air Rework Facility, Cherry Point, NC, as the Cognizant Field Activity (CFA) for C-130 aircraft, was tasked by the Naval Air Systems Command to provide planning data for a long term modification program to improve the operational safety of both the LC-130 F and LC-130 R aircraft.

OCEAN DRILLING

Question: What is the status of the Ocean Drilling program?

Answer: The Ocean Drilling program is fully operational. The drilling vessel JOIDES RESOLUTION completed her shakedown cruise on January 29 and began operations on January 31. Leg 101 of the ODP was successfully completed on March 14 after drilling at 11 sites in the vicinity of the Bahamas. Shipboard scientists from Leg 101 report that the drilling vessel is excellent and the modifications made in the shipyard have made her highly efficient. Leg 102, dedicated to downhole measurements and experiments, left Miami on March 19 for site 418 in the Western Atlantic, south of Bermuda.

Ancillary shore-based activities are operational and a new facility is under construction. Engineering development and logistics and technical support units are in operation at Texas A&M University. The downhole logging group is based at Lamont-Doherty Geological Observatory (L-DGO). Core repositories are functioning at L-DGO and Scripps Institution of Oceanography. The State of Texas has begun construction of a 10,000 square foot building at Texas A&M to house laboratories, offices, and a core repository.

Normal scientific planning is proceeding. Drilling targets are being developed in the following regions:

° 1985-86...North Atlantic, Mediterranean and East Pacific

° 1986-87...(Austral summer) Weddell Sea

° 1987-88...Indian Ocean and Western Pacific

Question: What is the status of the international commitment to this program?

Answer: The status of international commitment is as follows:

° France, the Federal Republic of Germany and Canada are full members of ODP. France and Germany have signed their Memoranda of Understanding (MOU's). Canada will sign on April 15, 1985.

° Japan will become a full member on or before October 1, 1985, and has signed an MOU which confers observer status on Japan until they formally join.

° The United Kingdom and the European Science Foundation consortium consisting of Norway, Sweden, Denmark, Belgium, the Netherlands, Switzerland, Italy, Spain and Greece are considering the same arrangement as Japan.

In last year's bill, the Congress added indemnification authority for this program.

Question: Does NSF believe it will be necessary to make permanent the indemnification authority provided by the Congress last year?

Answer: The legal advice that the Foundation has received is that the indemnification authority included in last year's bill is valid only for the life of the appropriation for new obligations, i.e., two years. Indemnification in NSF's contract with Joint Oceanographic Institutions, Inc. is limited accordingly.

MATERIALS DEVELOPMENT AND RESEARCH (SEE)

Materials Development and Research within the Education Directorate is operating in the current year at a level of $700,000 below that of FY 1984. This, of course, in part reflects the transfer of $5 million for learning and cognition research.

Question: How have you defined the break between research in the Education Directorate and that now within BBS?

Answer: Both BBS and SEE support projects that are intended to determine and analyze the factors critical to effective teaching and learning of mathematics and science. The research supported by BBS is somewhat more basic in character, whereas that supported by SEE is more directly related to the educational process itself. SEE projects are typically carried out in schools, either testing principles learned through more basic research (e.g., cognitive psychology) or involving substantial development of instructional materials and strategies.

Question: What mechanism do you have in place to assure that these activities are coordinated?

Answer: SEE and BBS activities are coordinated through a formal coordinating committee with both BBS and SEE representation. Many projects, moreover, receive joint consideration and joint support.

NUMBER OF AWARDS

Over the past two years, the Subcommittee has discussed with the Foundation the need to use some of the budget increase to support additional grants. I want to commend NSF in one respect. That is the estimated number of awards to be made in 1985 will exceed the total awards made in 1984 by almost 800. However, I am concerned because your estimate for 1986 is below your plan for 1985. In other words, it does not appear that NSF will be able to maintain a constant level of effort.

Question: Can you tell the Subcommittee what lies behind this?

Answer: It is true that the number of awards projected for FY 1986 (13,563) is below that estimated for FY 1985 (13,626). The difference, however, is less than 0.5%. The overall increase for the Foundation's budget--4.4%--essentially provides for a constant level program. In addition, increases for instrumentation and graduate students do not translate into additional awards, but rather into enhanced support for awards generally. Finally, programs such as Advanced Scientific Computing and Engineering Research Centers which receive substantial increases make a small number of large awards. Thus, the proposed budget level is as close to a constant level as the circumstances will permit.

Mr. Bloch, my concerns are driven by a belief that our education and research enterprise will benefit if we increase the opportunities available to scientists and engineers to participate in the research experience. One way to do this is to increase the number of grants. And while I'm not a scientist, I cannot help but believe that we as a society can improve our chances of finding solutions to critical problems if we increase the pool of people working on those problems.

Question: For the record, would you provide an estimate of what it would take to increase the number of awards for FY 1986 by 100, 150 and 200?

Answer: Grants for individual research project support, the dominant grant type of NSF, average about $70,000 depending upon the field of science. Thus an additional 100 awards would require $7 million; an additional 150 awards would require $10.5 million; and an additional 200 awards would require $14 million.

GRADUATE FELLOWSHIPS

The table on page QDT-52 of your justification indicates that 150 awards to various institutions will be made for Research Career Development in both FY 1985 and FY 1986, representing approximately 1,500 graduate fellowships. The justification narrative on page SEG-I-1, however, indicates that grantee students may study at institutions of their choice.

Question: Please explain the role the 150 institutions play in the administration of this program.

Answer: The reference to awards to institutions is a technicality. All Graduate Fellows have free choice of institution. After they have made their choice, the NSF makes grants to support them at their chosen institutions. These institutions, in turn, disburse the Fellows' stipends periodically. The Foundation's best estimate is that about 150 institutions will be selected in FY 1985 and FY 1986 by Graduate Fellows. The particular 150 institutions might change from year to year.

Question: What analysis has NSF undertaken to attempt to quantify the effectiveness of the graduate fellowship program?

Answer: The Foundation periodically conducts career achievement studies of Graduate Fellows. The last study, covering Fellows who began graduate school up to 1972, indicated, for example, that Graduate Fellows take 30% less time to complete the Ph.D. publish nearly 40% more, and are cited more than twice as often than the average Ph.D. in science. A similar study of more recent Fellows is now in progress.

COLLEGE SCIENCE INSTRUMENTATION PROGRAM

Last year, Congress added $5 million for instrumentation at four-year institutions.

Question: What is the status of this program?

Answer: The program is staffed and operating on or ahead of schedule. It was announced and proposals were invited in September with a closing date of January 11, 1985. Since that time, the 1,348 proposals received have been under peer review and staff analysis. We expect to announce approximately 200 awards by early June, in time for the instruments to be in place for the next academic year.

This program is virtually the only educational support provided for undergraduate education.

Question: What consideration is being given to additional programming for this segment of U.S. education?

Answer: We are looking closely at national needs and an appropriate NSF role in the area of undergraduate science, engineering and mathematics education. Staff analysis in this area continues, and it has been a discussion issue by the Directorate for Science and Engineering Education's Advisory Committee, and the NSF Executive Council. A National Science Board Task Group is being established to study this issue. It will be given full consideration in establishing priorities for the FY 1987 budget process.

ADVANCED SCIENTIFIC COMPUTING

Last month, NSF announced the establishment of three new supercomputer centers plus one experimental center.

Question: Can you give us your views on the importance of such centers?

Answer: These four centers are a major step in providing to scientists and engineers throughout the country the kind of supercomputing power needed to strengthen our research activities. Access to supercomputers will allow different approaches to problem solving, and will open up new research areas, that before were closed because of lack of adequate computing resources.

Question: What is NSF's long-range plan for its supercomputer initiative?

Answer: In the long term, we expect this initiative to provide a permanent solution to the supercomputer needs of the academic research community. Eventually, this may require ten centers connected to all other research institutions through a high quality network.

In last year's report, the Committee asked NSF to develop a "formal evaluation process for the supercomputer centers."

Question: What is the status of that activity?

Answer: An evaluation procedure has been developed for the NSF centers. This procedure was described in a letter to the Committee on April 1, 1985.

Question: What is the status of the transfer of the NASA supercomputer to NSF?

Answer: The Cray 1S supercomputer, currently at the NASA/Lewis Research Center, will be transferred to a university chosen by NSF in the fall of 1985. We are currently carrying out the process of deciding which university this will be.

Question: Should other Federally owned or leased supercomputers become available, would NSF be able to make use of the machines within its supercomputer program?

Answer: If funds could be provided to maintain, operate and configure them, such machines could be a valuable part of the NSF program. However, given the rapid rate of advances in supercomputer capability some provision for upgrading these computers in the near future may be necessary to achieve the maximum benefit from the considerable investment in operating expenses that is necessary for a supercomputer center.

Question: Have you identified or discussed the possibility of acquiring supercomputers currently in use by other Federal agencies?

Answer: So far we have not identified, nor has any Federal agency indicated to us, any supercomputer which will not be fully utilized in the foreseeable future. Therefore, we don't see any such machines being available for transfer in the near future.

OMB REQUEST

Question: Please submit, for the record, a table containing your initial request to OMB for FY 1986 and the levels contained in your FY 1986 budget request. Please use the same level of detail as appears on pages NSF-30 through NSF-39 of your budget justification.

Answer: (SEE THE FOLLOWING TABLES)

NATIONAL SCIENCE FOUNDATION
COMPARISON OF FY 1986 OMB REQUEST
TO THE CONGRESSIONAL REQUEST
(Dollars in Thousands)

	FY 1986 1/ Request to OMB	FY 1986 Request to Congress	Difference Cong/OMB
MATHEMATICAL AND PHYSICAL SCIENCES			
Mathematical Sciences	$58,000	$54,690	($3,310)
Computer Research	48,400	41,730	(6,670)
Physics	132,200	123,370	(8,830)
Chemistry	100,400	93,500	(6,900)
Materials Research	122,500	115,680	(6,820)
Subtotal, MPS	461,500	428,970	(32,530)
ENGINEERING			
Electrical, Computer, and Systems Engineering	45,600		
Chemical and Process Engineering	33,900		
Civil and Environmental Engineering	35,800		
Mechanical Engineering and Applied Mechanics	26,100		
Engineering Research Centers	50,400	(25,000)2/	
Chemical, Biochemical, and Thermal Engineering		29,360	
Mechanics, Structures, and Materials Engineering		23,650	
Electrical, Communications, and Systems Engineering		26,680	
Design, Manufacturing, and Computer Engineering		20,390	
Emerging and Critical Engineering Systems		38,500	
Cross-Disciplinary Research		31,490	
Subtotal, ENG	191,800	170,070	(21,730)
BIOLOGICAL, BEHAVIORAL, AND SOCIAL SCIENCES			
Molecular Biosciences	$70,700	$64,130	($6,570)
Cellular Biosciences	61,600	54,380	(7,220)
Biotic Systems and Resources	65,900	63,020	(2,880)
Behavioral and Neural Sciences	51,000	47,130	(3,870)
Social and Economic Science	35,300	33,890	(1,410)
Information Science and and Technology	10,700	9,500	(1,200)
Subtotal, BBS	295,200	272,050	(23,150)
ASTRONOMICAL, ATMOSPHERIC, EARTH AND OCEAN SCIENCES			
Astronomical Sciences	95,400	88,670	(6,730)
Atmospheric Sciences	109,400	97,640	(11,760)
Earth Sciences	69,800	51,500	(18,300)
Ocean Sciences	139,600	125,580	(14,020)
Arctic Research Program	8,200	8,780	580
Subtotal, AAEO	422,400	372,170	(50,230)
SCIENTIFIC, TECHNOLOGICAL AND INTERNATIONAL AFFAIRS			
Industrial Science and Technological Innovation	30,300	13,300	(17,000)
International Cooperative Scientific Activities	9,500	12,090	2,590
Policy Research and Analysis	5,200	1,990	(3,210)
Science Resources Studies	4,800	3,990	(810)
Research Initiation and Improvement	15,300	6,990	(8,310)
Subtotal, STIA	65,100	38,360	(26,740)

NATIONAL SCIENCE FOUNDATION
COMPARISON OF FY 1986 OMB REQUEST
TO THE CONGRESSIONAL REQUEST
(Dollars in Thousands)
(Continued)

	FY 1986 1/ Request to OMB	FY 1986 Request to Congress	Difference Cong/OMB
ADVANCED SCIENTIFIC COMPUTING	$61,800	$46,230	($15,570)
PROGRAM DEVELOPMENT AND MANAGEMENT	79,100	69,900	(9,200)
TOTAL, RESEARCH AND RELATED ACTIVITIES	$1,576,900	$1,397,750	($179,150)
U.S. ANTARCTIC PROGRAM			
U.S. Antarctic Research Program	11,500	11,500	0
Operations Support	108,600	108,600	0
TOTAL, U.S. ANTARCTIC PROGRAM	$120,100	$120,100	$0
SCIENCE AND ENGINEERING EDUCATION ACTIVITIES			
Graduate Research Fellowships	28,500		
Pre-College Science and Mathematics Education	62,100		
Undergraduate Program	25,200		
Research Career Development		27,300	
College Science Instrumentation		5,000	
Materials Development and Research Improvement		22,700	
Teacher Enhancement and Informal Science Education		25,000	
Studies and Program Assessment		2,000	
TOTAL, SCIENCE AND ENGINEERING EDUCATION ACTIVITIES	$115,800	$82,000	($33,800)
SPECIAL FOREIGN CURRENCY PROGRAM	3,000	1,000	(2,000)
TOTAL, NATIONAL SCIENCE FOUNDATION	$1,815,800	$1,600,850	($214,950)

1/ The FY 1986 Request to OMB does not reflect programmatic changes included in the FY 1986 Request to Congress; i.e., Research Opportunities for Women, Minority Research Initiation, Experimental Program to Stimulate Competitive Research, Industry/University Projects and Centers, and International Cooperative Sciences.

2/ Included under Cross-Disciplinary Research together with Industry/University Cooperative Research Centers and Projects.

FOREIGN STUDENTS

Recent surveys have indicated that 50% of all engineering Ph.D.s granted by universities in this country are going to foreign students.

Question: As Director of NSF, does this concern you and, if so, what steps can be taken to address this issue?

Answer: The percentage of foreign students in U.S. engineering graduate schools is high, exceeding 40 percent in most fields.

However, NSF is more concerned about the reasons for the low number of U.S. graduate students in certain fields, especially engineering, rather than the number or percentage of foreign students in engineering graduate schools. Exposing students from other nations to life in the U.S. and its democratic values has been a positive force for strengthening U.S. ties with other nations. Nevertheless, it is imperative that the U.S. have sufficient numbers of U.S. students pursuing advanced degrees in science and engineering in order to insure our future security and economic vitality.

For example, without sufficient manpower, our defense industries will suffer because these firms must use only U.S. citizens on classified defense projects. The Defense Department has become so concerned about the level of foreign graduate students that all three services have, or are about to, implement Graduate Fellowship programs that are designed to expand the pool of U.S. students pursuing the Ph.D. degree in fields most closely aligned with Defense Department missions.

The NSF Presidential Young Investigator's (PYI) program, which is available only to U.S. citizens, is partly a response to the need to provide more incentives for U.S. students to seek a faculty career in engineering and other key fields. Since 1984, when the program was implemented, the National Science Foundation has made about 400 PYI awards, and half of that total have gone to young faculty engineers.

The Foundation believes that there is still a need to provide further incentives for U.S. students to obtain advanced degrees in science and engineering and we are studying options for achieving this objective. The recently established Engineering Research Centers program is designed to provide this incentive. Each of the Centers will provide research opportunities for both graduate and undergraduate engineering students and since the Centers are designed to help maintain U.S. industrial competitiveness over the long term, U.S. students are expected to be major beneficiaries of the program.

SCIENTISTS & ENGINEERS DEMAND

Question: Could you please provide, for the record, your current estimate of the supply of and demand for scientists and engineers by discipline for the next decade?

Answer: In 1984, the Foundation published a projection study designed to assess the impact of the defense buildup on the science, engineering, and technician labor (SET) market over the 1982-87 period. The study analyzed results from four projection scenarios which matched various combinations of low- and high-economic growth (annual growth in gross national product (GNP) ranging from 1.6 percent to 4.3 percent) with low- and high-growth rates in real defense expenditures (3.1 percent to 8.1 percent). To date, the Foundation has not extended its projections beyond 1987.

Three occupations were identified to have potential personnel shortages in 1987 given increasing demands being made on the SET labor force resulting from increased defense and non-defense requirements. These included aeronautical/astronautical engineering, computer specialties (including systems analysis and programming), and electrical/electronics engineering. The study found that new degree production in these fields would be inadequate to meet the rapid growth in requirements by 1987. It was estimated, however, that the inflow of workers from other occupations in response to expanding job opportunities and wage incentives could relieve actual personnel shortages. The sustained, high rates of inflow which were needed to equilibrate demand and supply could jeopardize the quality of the work forces in these occupations; such quality downgrading is also a manifestation of labor shortages.

The projected labor market situation for 1987 by discipline is:

(SEE THE FOLLOWING TABLE)

Field	1987 demand	1987 supply	Shortage(-)/ surplus(+)	1987 demand	1987 supply	Shortage(-)/ surplus(+)
	(In thousands)					
	(Low-economic growth/ low-defense expenditures)			(High-economic growth/ high-defense expenditures)		
Total, scientists	555.9	612.1	56.2	584.7	639.9	55.2
Agricultural	17.3	21.2	3.9	19.4	22.2	3.8
Biologists	59.4	73.1	13.7	62.5	76.3	13.8
Chemists	97.7	99.8	2.1	102.8	104.6	1.8
Geologists	47.9	51.6	3.7	47.9	51.6	3.7
Mathematical	56.9	59.6	2.7	60.6	63.0	2.4
Physicists	22.4	24.9	2.5	24.2	26.6	2.4
Other life/ physical	29.5	31.5	2.0	31.3	33.3	2.0
Social	224.8	250.4	25.6	237.0	262.3	25.3
Total, engineers	1,296.4	1,319.1	22.7	1,423.1	1,437.3	14.2
Aeronautical	85.5	83.6	-1.9	109.2	104.8	-4.4
Chemical	57.4	60.8	3.4	60.9	64.2	3.3
Civil	174.7	177.0	2.3	188.9	190.1	1.2
Electrical/ electronics	396.3	397.9	1.6	420.6	421.3	.7
Industrial	120.3	120.2	-.1	130.8	129.8	-1.0
Mechanical	223.9	230.5	6.6	248.2	253.4	5.2
Metallurgical	16.3	17.1	.8	18.5	19.2	.7
Mining/petroleum	31.7	32.6	.9	31.6	32.5	.9
Other engineering	190.3	199.4	9.1	214.4	222.0	7.6
Computer specialists	577.6	568.4	-9.2	603.8	592.8	-11.0

SOURCE: National Science Foundation, Projected Response of the Science, Engineering, and Technician Labor Market to Defense and Nondefense Needs: 1982-87, (NSF 84-304) (Washington, D.C., 1984).

QUESTIONS SUBMITTED BY SENATOR DOMENICI

SCIENCE AND MATH EDUCATION

Question: Does NSF's FY 1986 request for appropriations include funding for the math and science teacher scholarship program authorized under the Education for Economic Security Act?

Answer: No. Funding for this program is not being requested in the Foundation's FY 1986 budget.

Question: If the Congress appropriated money for this program this year, how long would it take the NSF to distribute it?

Answer: Approximately on year. The principal steps would be:

° development of guidelines;
° approval by the National Science Board;
° announcement of program, followed by submission of applications;
° evaluation of applications; and
° selection of awardees.

A complicating factor is that awards should optimally be made no later than March in order to affect college plans.

Question: Have you moved ahead with your planning, as I suggested several months ago?

Answer: As you know no appropriations accompanied the math and science teacher scholarship program authorized by the Education for Economic Security Act. For that reason, we have not taken steps to implement that particular program. However, should the Congress appropriate funds for this particular program in FY 1986, NSF would move forward with this program as expeditiously as possible.

The people at NSF are aware of the fact that universities are now coming to the Congress for new facilities. I think that is, in part, because NSF does little in this regard, and what they do, is done with the "same old universities." The main problem with universities coming to the Congress is that it is those "same old universities" who are getting their way.

Obviously, universities are coming to us because there is a need. In DOE we have a problem to keep existing facilities in good shape and build new ones where the need exists. This program was set up after a "survey of needs."

Question: The NSF and the National Science Board have been saying we need to strengthen "peer review" but I do not believe you actually have a program in which to use peer review. I believe those programs ended in the 60's. Is that correct?

Answer: During the time period FY 1960 to FY 1972, NSF provided funds specifically for renovation and construction through two programs: Graduate Science Facilities and University Science Development. They were terminated in FY 1970 and FY 1972 respectively.

Question: Don't we need to do a National Survey?

Answer: The White House Science Council's Committee on the Health of Universities (also known as the Packard/Bromley Committee) has undertaken a study of all factors central to the health of academic research and training capability, including academic research facilities. Their report, which is expected to contain significant policy statements and recommendations, will be issued this summer. We expect that there will be general agreement that the cost of improving current university facilities is large (in the range of perhaps $50 billion). We don't believe that a study to document the need further is necessary to guide policy makers. The central issue is what is the role of the Federal government as well as the roles of universities, state and local governments, and the private sector in providing support for improving academic facilities. We strongly recommend that the Parkard/Bromley study be evaluated prior to committing to a National Survey.

Question: Don't we need to set up a program?

Answer: During a period of severe budget constraint, the role of the Federal government in dealing with the university facilities issue must necessarily be very limited. Consistent with this view, in FY 1986, the Foundation intends to provide some very limited funding for renovation and construction of new space as part of its three major research initiatives: Engineering Research Centers, Biotechnology, and Advanced Scientific Computing. In each case the facilities funding must be necessary for the activities being proposed.

QUESTIONS SUBMITTED BY SENATOR CHILES

I am concerned about the proposed deferral of Science and Engineering Education Funds. This $31.5 million would be spent on teacher enhancement, information science education, and materials development and research.

Question: Since Congress has been appropriating funds to NSF for science and math education for a number of years, and provided $75 million in fiscal year 1984 for these same kinds of activities, why isn't the pipeline ready to handle the 1985 funds?

Answer: The Foundation is making a strong attempt to ensure that funds for science and engineering education are expended in the most prudent and effective manner. A major limiting factor at this point is the development of a comprehensive long range plan for building a coherent program that will effectively couple NSF's relatively small effort to the massive $144.5 billion annual investment being made in precollege education by other Federal agencies, and by state, local and private sources. In 1985, Congress set aside $2.0 million for this purpose, and we will go out this Spring with the first round of proposals. This planning effort is crucial if we are to build a stable foundation for activities in the future.

We have already funded many excellent proposals. But I must point out that even a collection of excellent proposals does not necessarily make a cohesive program that is effectively coupled to the Nation's schools and teachers. I believe that as our program objectives are more clearly defined through the planning process, more focussed proposals will be submitted and funded.

Currently, however, we cannot prudently obligate in FY 1985 all of the funds available in the precollege programs. Thus, we are proposing to carry over $31.5 million as a planned deferral into FY 1986.

I want to emphasize that education and human resources are among my chief concerns. I am committed to building a stable precollege science education program that provides national leadership and serves as a catalyst for other Federal, state, and local programs. My decision to carry forward funds that cannot be effectively obligated in 1985 does not jeopardize that commitment.

Question: The $31.5 million appropriated for science and engineering activities by the NSF was part of an overall initiative, including the Department of Education, to help the states and local education agencies enhance and improve math and science instruction. Congress believed that the NSF should have an integral part in curriculum development and teacher training. What needs to be done to get this program, your part of it anyway, implemented? What does the deferral accomplish in terms of better science and engineering programs?

Answer: NSF is implementing the Congressional mandate to work on curriculum materials development and teacher training, and the relevant programs are well underway. The Division of Teacher Enhancement and Informal Science Education will obligate about $15 million in FY 1985 on various teacher training model programs, and the Division of Materials Development and Research will obligate about $12 million for the development of instructional materials for both students and teachers and the support of model programs to improve the preparation of teachers. The deferral represents funds beyond these levels. Its purpose is to allow NSF to fund only the very best projects and to do so in a responsible, deliberate and thoughtful way that will result in the best mix of projects to meet the needs of the educational system. The deferral is a protection against the danger of rushing to obligate funds in a imprudent manner, particularly in this time of need for fiscal restraint. Moving more slowly will allow greater attention to the development, review selection and refinement of projects for NSF support, and thereby maximize the impact of the funds that are expended.

One of the problems we had with the texts and materials from NSF development under the National Defense Education Act was that "good science and math" did not always translate into texts and curricula incorporating good teaching methodology that teachers and the average or below student understood.

Question: To what extent, if any, are you collaborating with the Department of Education to insure sound pedagogy goes hand-and-hand with sound scientific and mathematical principles in the materials that are developed through these grants? How are you involving educational experts in curriculum development, the cognitive learning process, and teaching methods in the grants process? Does your request for proposals require this type of collaboration?

Answer: We share the serious concern about the need to guarantee pedagogical as well as scientific validity in the materials and other projects we support. Our program announcements urge the active collaboration of practicing scientists with science educators in universities and practicing educators at the local level. NSF is in a unique position -- on which we capitalize -- to foster these collaborations by virtue of its extensive contacts in the relevant communities. Our announced project selection criteria further emphasize this point. We require evidence of both scientific content and pedagogical validity in the proposals support. NSF does coordinate its efforts with similar efforts in DoEd.

Question: Are you focusing on development of materials for all levels of students and training teachers in the skills they need to teach math and science to the full range of students?

Answer: We are supporting projects directed at all levels and backgrounds of students and teachers. Some projects are relevant to all educational levels in some way, whereas other projects are directed at specific groups of students either by grade level or by socioeconomic or ethnic background. Principal among our target groups are female students, disadvantaged minorities, and the physically handicapped.

BIOTECHNOLOGY

Question: As you know, the Cabinet Council Working Group on Biotechnology recently issued its proposal for a framework for regulation of biotechnology. What was NSF's role in this effort and what is your opinion of the proposal?

Answer: The National Science Foundation, through the Directorate for Biological, Behavioral, and Social Sciences (BBS), has been an active participant in the biotechnology working group of the Cabinet Council on Natural Resources and the Environment since it was formed in April, 1984. Through this working group, NSF has had the opportunity to share its scientific experience with the regulatory agencies and has been a full participant in the drafting of the Cabinet Council's proposed regulatory framework. The Foundation endorses the approach taken by the Cabinet Council Working Group, especially the concept of sound scientific risk assessment by a broad based committee not concerned with regulation but focusing principally on the assessment of potential risks.

Question: Are the existing laws and regulatory structure sufficient to handle the evolution of this technology from the laboratory to the marketplace in your opinion?

Answer: The matrix of the existing regulatory statutes that was presented in the Federal Register as part of the Cabinet Council's proposal does not reveal any major gaps in regulatory responsibility. There are a few areas of overlapping jurisdiction but this situation is not unique to biotechnology. Given the planned transformation of the Cabinet Council Working Group into an interagency panel for regulatory coordination it is very likely that this group will identify any regulatory gaps that appear in the future. Now that the original ninety day comment period on the proposed regulatory framework has expired, the Working Group will reexamine the proposal prior to the issuance of the final guidelines.

Question: Is the public's health and well-being assured under this system?

Answer: Most definitely, yes.

Question: Are you concerned the existing regulatory framework may be overly burdensome to companies trying to get biotechnology products on the market?

Answer: The Cabinet Council proposal was based on existing statutes with the goal of providing a guideline for industry as they bring products forward. The fear is not that the framework may be overly burdensome, but that delays in implementing this plan, compounded with several recent court actions, may discourage industry, especially the smaller companies, from undertaking projects which fall into the controversial areas. The possible loss of these products to foreign firms which have fewer barriers to overcome is a concern.

Question: How could this framework be streamlined without compromising public health and safety?

Answer: There are two parts of the proposed regulatory framework which deserve further review and these will no doubt be addressed during the final revision of the document. First, there is the feeling that clearer guidance is necessary in defining the agency responsible for a given group of projects and that examples of the submission procedure would be useful. Second, the process of the two-tier scientific risk assessment may be streamlined through the revision of the basic review process. This reexamination is currently underway within the Working Group itself.

Question: Obviously, the release of novel substances and organisms raises some interesting questions. Critics contend we do not have enough basic knowledge or a sufficient data base regarding the interaction of these new products and the environment to allow their release at this time. Is NSF either funding or actually doing any basic or generic risk assessment research regarding genetically engineered products? If so, would you tell me about this research, the commitment in terms of manpower and funding and whether new efforts in this area will be made in the future.

Answer: NSF participates in the area of risk assessment modeling and methodology. First, at least two NSF programs support a broad range of research in generic risk assessment. This work includes concepts of risk assessment modeling and methodology. Second, through the Division of Biotic Systems and Resources in BBS, NSF has been the major supporter of all forms of research in systematics and ecology which form the data base for scientific risk assessment. In the past three years, the Foundation has made approximately twenty grant awards directly related to microbial ecology and an additional eleven in bacterial systematics which support the development of modern technologies for the identification, classification and tracking of a microorganism in a given ecosystem. NSF has continued to expand its activities in this area through the sponsorship or co-sponsorship of scientific symposia which bring together ecologists and molecular biologists to discuss questions regarding the environmental release of microorganisms with defined properties.

The total NSF activity related to the specific question of risk assessment in biotechnology is difficult to assess, however, a review of the activities mentioned above, provides a current activity of approximately twenty-five awards at a funding commitment of approximately $3.0 million. This money supports a number of investigators in universities, research foundations and for-profit contractors.

Question: How does the NSF funding level for biotechnology risk assessment compare to the NSF funding level for other types of biotechnology research?

Answer: The answer to this question depends on the agreement of the applicability of a given research project to biotechnology risk assessment. At the present time it would be fair to estimate that the level of support for research related to biotechnology risk assessment is approximately five percent of the total support for biotechnology related research. The total support for biotechnology related research is expected to reach approximately $70 million in FY 1985.

Question: In your opinion, do we know enough now about the basic risk elements of biotechnology to develop a good regulatory framework?

Answer: The NSF programs throughout the Division of Biotic Systems and Resources have been supporting work which has been adding to a considerable data base from which to assess the effects of new organisms on the environment. A number of related programs in systematics and ecosystem studies provide a great deal of information upon which to base the scientific assessment of risk in biotechnology. There is is little question that further research is needed to give all of the information necessary for fully informed regulation. However, the data base currently available is adequate for the formation of a good and solidly based regulatory framework at this time.

Question: In your opinion, what is an acceptable level of risk for the release of biotechnology products? Can we put a number on it in a manner similar to the way we assess financial risk, for example?

Answer: It is difficult to state what is an "acceptable risk" for an unspecified product. The available information suggests that the risk from biotechnology products is rather low. In the area of new agricultural food crops the risk appears to be very low. In the area of microorganisms that are capable of degrading petroleum as a means of clearing oil spills, the potential environmental damage could be worse than the spill itself and may well be unacceptable. The potential of an environmental disruption from a biotechnology accident is probably less than that from the loss of an oil-bearing super tanker which is low enough to be insurable through commercial underwriters. The worst economic impact and, therefore, the risk evaluation figure, would probably be proportionally less.

Question: Are some types of genetically engineered products or substances inherently riskier than others?

Answer: This question gets to the heart of much of the misunderstanding regarding regulation of the biotechnology industry. Pharmaceuticals produced by genetically engineered cells are no different than those produced by normal cells, only the process is different. Most biotechnology "products" are not living, replicating organisms but normal compounds already found in nature and which in themselves are not harmful and pose no environmental threat. Potential environmental impacts result from the release of living, replicating organisms. This release of living organisms would only apply to agricultural food plants and to microorganisms used for a variety of purposes such as pesticides or for environmental decontamination. The new plant varieties appear to represent no greater threat than the hybrid plants introduced into our agricultural system for many years. The directed application of microorganisms into the environment has a much greater potential for negative consequences and must be carefully evaluated.

Question: What are the relative generic problems associated with the release of novel organisms?

Answer: The generic problems of the introduction of a new organism into an ecological niche all center on the ability of the organism to become established in that niche and whether it is able to spread from that local area. The basic principles of ecology, which include the resistance of the organisms to environmental effects, the effects of predation and of inter-organismic interactions will apply to genetically altered organisms in the same way they apply to naturally occurring species.

Question: Do you think we will ever have a totally complete predictive model for assessing the environmental effects of biotechnology releases?

Answer: Such a model will be very product sensitive and at present there is very little way to predict the full range of biotechnology applications. Since the vast majority of biotechnology derived products appear to have no environmental implications, it may be possible to derive a model for several classes of living products. Additional research will be needed to provide the basis for that model. Until that time, evaluation will have to be made on a case-by-case basis.

Question: Once release has occurred, how is monitoring done? Will different releases require different monitoring systems?

Answer: The technology that has produced the genetically altered organisms has also provided the means to introduce into those organisms specific markers to enable easy monitoring in the environment. This monitoring involves quantitative examination of the release site and surrounding areas for the appearance of the newly released organism. Because of the potentially diverse environments into which a new organism may be introduced (i.e. aquatic, marine, terrestrial) different monitoring regimens will be necessary, however, the basic technology will remain constant.

Question: Is any research regarding post-release monitoring being done?

Answer: Yes. Research related to this question is included in a number of studies involving microbial ecology and systematics. In addition, this monitoring problem is very much like the classic undertaking of medical epidemiology of infectious diseases where a considerable battery of techniques is available.

Question: Are any other agencies engaged in risk assessment research on genetically-engineered products or substances to your knowledge? If so, which ones?

Answer: The Environmental Protection Agency supports research related to the problem of risk assessment of altered organisms. The U.S. Department of Agriculture has published plans to initiate work in this area.

Question: Are these research efforts coordinated in any way with work being done at NSF?

Answer: Yes. Two mechanisms of coordination are used. First, the Cabinet Council Working Group has a subcommittee for research and development which is cataloging all of the Federal research activity. This group is chaired by the NSF member of the Working Group. Second, coordination occurs through the interagency working group on plant sciences.

QUESTIONS SUBMITTED BY SENATOR LEAHY

On page NSF-2 of your budget justification, you list "increased support for research related to long-term U.S. economic competitiveness" as the Foundation's first priority.

On the next page, you stated that Productivity Improvement Research will be terminated.

Question: Is this consistent? Is not the productivity decline one of the central reasons for the U.S.'s weakening competitive position?

Answer: I agree that productivity plays a key role in our economic competitiveness. The basic scientific and engineering research supported by the Foundation directly and indirectly contributes to productivity improvement and thus provides the underpinnings for maintaining and improving our competitive base. The objective of the Productivity Improvement Research (PIR) program is to improve the understanding of the innovative processes, particularly as they are affected by management practices and Federal actions. With the increased emphasis in our Engineering program on engineering design and systems integration, the need for a separately budgeted activity such as PIR is greatly reduced.

Question: Last year, Congress created an Arctic Research Commission. Is funding of this new organization for fiscal year 1986 included in the NSF budget?

Will it be an independent organization or an NSF program?

Answer: The Arctic Research Commission, authorized by the Arctic Research and Policy Act of 1984, is an independent federal entity, not an NSF program. The Commission was established January 28, 1985, by Executive Order; its members were sworn in March 1, 1985.

The Arctic Research and Policy Act designates NSF as "the lead agency responsible for implementing Arctic research policy." In partial fulfillment of this responsibility, NSF signed an interagency agreement with the Commission to permit it to begin to function as soon as its members were sworn in. This agreement provides some of the funds the Commission needs to conduct its affairs through the remainder of FY 1985.

Though the Commission is an independent federal entity, at the time the NSF budget was prepared, it was uncertain when the Commission would begin to function. Thus it could not submit a budget request. Consequently, NSF included in its FY 1986 budget proposal $680,000 for Arctic Research and Policy Act implementation, of which $300,000 has been earmarked to support the Commission during that year.

On page NSF-5 of your budget justification, you state that in 1986 you will curtail "...programs that are not in the mainstream of science and engineering research and education".

Question: What objective criteria does the Foundation use to curtail programs "not in the mainstream..."?

Answer: There is no set of hard and fast criteria we used to curtail or reduce programs 'not in the mainstream'. In a period of fiscal constraint, one must carefully look at all programs, and make hard decisions as to whether one program should continue or even increase at the expense of another.

Our first priority was to protect basic scientific and engineering research, and the people, equipment and facilities that are integral part of that research infrastructure. Within this context, directorates looked carefully at their core programs, and found some areas of research that could be reduced to some extent because either research opportunities were waning, events had overtaken them, or perhaps industry had provided adequate support. This is one context of 'not in the mainstream'.

We also looked at programs that had been set up to nurture research efforts in a particular area, or perhaps even particular groups. Some of these efforts should be brought into the mainstream, i.e., they had developed to the point where they should compete against other proposals. In this context, 'not in the mainstream' means that the special program was terminated and the proposals must now compete for funding in the appropriate research area. In some cases, the competitive area received an increase to accommodate the additional proposals.

In yet other cases, such as Intergovernmental Science and Technology, the programs had been marked earlier for termination or phase-down.

Question: For each program curtailed, please state how it was out of the "mainstream."

Answer: The following list of reduced or terminated programs is indicative of how and why the decision was made.

Research Initiation Grants (RIG) - Program to support young engineers which has been replaced by the Presidential Young Investigator (PYI) awards. Under the PYI program, 50% of the awardees must be engineers, which means that by 1986, 250 young engineers will be supported as PYI's, much higher than under the RIG program. Moreover, PYI funding is higher and provides for industry matching.

Alternative Biological Resources (ABR) - There are two major reasons for eliminating ABR. The program's focus on the use of biological systems as alternative sources of chemicals and materials represents applied research that is generally considered more appropriate for mission agencies such as DOE and USDA. The ABR Program has been a very small effort at NSF, with much larger investments in closely-related areas by the mission agencies. A second aspect is that the disciplinary programs in biology at NSF can as effectively evaluate the appropriate fundamental research that ABR now handles, and the overhead associated with a separate program is unnecessary.

Regulation and Policy Analysis - Abolished to emphasize a shift to more fundamental economic research. Continuing grants will still be funded in the Political and Policy Sciences area.

Ethics and Values in Science and Technology - Has existed as a separate program element since 1976, and has been effective in increasing the awareness of the importance of ethical and values issues. Many of its projects are now self-supporting, and have been instrumental in stimulating professional societies to take a more active role in addressing these issues. The concept of the program has been demonstrated, and there is, in my opinion, no longer a need for a special program. Fundamental research topics in ethics and values are eligible to compete in other areas of the Foundation, particularly in the Social and

Economic Sciences area.

Intergovernmental Science and Technology - Initial phase-down began in 1982 when the program was substantially cut back. Phase out was expected to last approximately three years.

Societal Response Earthquake Program - Discontinued as a program with a separate budget, but since it is an integral part of earthquake engineering and hazard mitigation, it will continue to receive attention in the program. Moreover, U.S. Geological Survey (USGS) and Federal Emergency Management Agency (FEMA) have activities that address these types of issues.

Some reduced or terminated programs such as Productivity Research Improvement and Policy Research and Analysis are dealt with specifically and in greater detail in response to other questions.

SCIENCE AND ENGINEERING EDUCATION

The Administration has proposed a $31.5 million deferral for the Directorate of Science and Engineering Education (SEE). The proposed NSF Budget has been increased from $1.5 billion to $1.6 billion with only the SEE budget being cut. The Director of NSF testified on February 21, 1985, that he asked for more money for the SEE, but because he did not receive an increased budget from the Office of Management and Budget (OMB), he now reports that he cannot spend the currently appropriated funds. The $31.5 million deferral is to be equally split between teacher enhancement and information science education and the materials development and research activities.

Question: Last year, the Directorate received funds for the express purpose of putting in place a reorganization plan.

(a) Is the reorganization plan in place?

Answer: The funds directed last year toward the development of a management plan for the Directorate are now in the process of being expended. The Directorate has, however, simultaneously established an organizational structure and sets of operating procedures designed to expend the funds appropriated and put a long-range plan in place as soon as possible.

(b) Is the Directorate operating at full capacity?

Answer: The Directorate is not yet operating at full capacity. The Division of Teacher Enhancement and Informal Science Education has just reached full staffing levels, but the Division of Materials Development and Research still has three program officer vacancies.

(c) What is the structure and mechanism for reviewing, administering, and managing contracts and grants?

Answer: The structure and mechanism for reviewing, administering, and managing contracts and grants uses a combination of panel review (for the graduate and minority graduate fellowship programs and the College Science Instrumentation Program) and ad hoc peer review combined with panel review for the Materials Development and Research and Teacher Enhancement and Informal Science Education proposals.

The reorganization of the Science and Engineering Education Directorate reflects a change in approach by emphasizing the support of programs in a strategic fashion. There are three divisions and two offices.

At the precollege level, these are:

The Division of Materials Development and Research, which includes:

- Instructional Materials Development;
- Materials and Methods for Teacher Preparation;
- Applications of Advanced Technologies; and
- Research in Teaching and Learning.

The Division of Teacher Enhancement and Informal Science Education, which includes:

- Presidential Awards for Excellence in Science & Mathematics Teaching;
- Leadership Activities for Precollege Teachers;
- Local and Regional Teacher Development;
- Informal Science Education; and
- Information in Science and Mathematics Education.

The Office of Studies and Program Assessment, which collects and disseminates information on the status of mathematics, science, and technology education in the U.S., determines the impact and outcomes of past and present NSF support for science education, and encourages partnerships, especially with industry, to strengthen science and engineering education.

At the undergraduate level, the Office of College Science Instrumentation is a program for 4-year colleges to support laboratory instrumentation in an instructional context.

At the graduate level, the Division of Research Career Development includes:

- The Graduate Research Fellowship Program;
- Minority Graduate Research Fellowship Program; and
- NATO Postdoctoral Research Awards.

(d) Is this process running smoothly, i.e., is the Directorate handling proposals and applications in a timely manner?

Answer: Proposal processing is proceeding smoothly and in a timely manner. We have conquered the backlogs that plagued the Foundation in the past because of insufficient staff. We have now turned to the important issues of strategic planning and strategic selection of projects to support.

Question: What kinds of initiatives would be affected if the $31.5 million from FY 1985 is deferred until next year?

Answer: No initiatives were proposed in FY 1985 in the precollege programs. The deferral would curtail the number of proposals funded in FY 1985 in the ongoing precollege programs.

Question: How many proposals with what total dollar amount do you currently have on hand in response to the Directorate's March 1984 program announcement?

Answer: As of March 31, 1985, the precollege programs have 526 proposals pending in-house valued at $228 million. Nearly all of these proposals were prepared prior to the issuance of the new program announcement.

Question: How would you rate the majority of those proposals?

Answer: Since the proposals are received daily and are in varying stages of review, it is not possible to say with certainty how many are of what quality. Based on past experience, we would estimate that the review will reveal approximately half are deserving of support based on merit alone. However, as I have indicated in response to other questions, in the science education area, we are looking not only for good proposals, but good proposals that are or can be effectively integrated into the ongoing educational efforts of states and localities.

Question: How long would it take the Directorate for Science and Engineering Education and the Foundation to review and fund the worthy proposals?

Answer: The science education proposals require essentially the same amount of time for processing as proposals to the other NSF programs, about 6-9 months.

In your Technology Assessment and Risk Analysis program you funded a study of methods of improving the performance of the Consumer Products Safety Commission's (CPSC) regulation.

Question: What were the particular findings of the study?

Answer: The particular findings of the study, funded by NSF's Regulation and Policy Analysis Program, were that a possible counter productive effect of safety regulations exists. That effect could occur if consumers were "lulled" into a false sense of security by the regulations. The study tested for such an effect by empirically examining the relation between the 1972 Food & Drug Administration regulation mandating safety caps and aspirin poisoning rates. In addition, the study examined available data relating to a number of CPSC regulations, including those relating to the safety of cribs, carpets, matches, bicycles and mattresses. The study produced evidence that most of the safety regulations had either counterproductive effects or no effects.

Question: Were they communicated in a formal method by NSF to CPSC?

Answer: NSF did not, in a formal way, communicate the findings of the study to the CPSC. However, two articles based on the study have been published or submitted for publication. These are: Viscusi, W. Kip, "The Lulling Effect: The Impact of Protective

Bottlecaps on Aspirin and Analgesic Ingestions," American Economic Review Papers and Proceedings. Vol. 84, No. 2 (1984), pp. 324-327; and, Viscusi, W. Kip, "Consumer Behavior and the Safety Impacts of Product Safety Regulation," Journal of Law and Economics, (Forthcoming).

Question: Did the study improve CPSC regulation?

Answer: NSF has no knowledge, at present, whether CPSC has taken any action based on the study results.

ASTRONOMY

On page AAEO-I-2 of your budget justification, you mention that NASA and DOD also engage in astronomy research.

Question: Please provide a chart comparing astronomy funding for all three agencies from 1980-1986.

Answer:

Funding for Astronomy Research
from NSF, NASA, and DOD
(In Millions of Dollars)

						(Est)	(Est.)
	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86
NSF	$56.6	$58.4	$ 59.1	$ 62.7	$ 77.3	$ 83.0	$ 88.7
DOD*	13.2	14.6	17.0	17.1	16.2	20.2	23.1
NASA*	229.7	198.7	184.6	265.7	303.1	331.4	308.0
-Ground-based	(10.9)	(11.4)	(9.4)	(10.3)	(11.1)	(11.4)	(12.7)

* Figures from NSF Division of Science Resources Studies

ASTRONOMY

Both NSF and NASA have astronomy programs doing basic research.

Question: Has this or any other administration ever considered merging these two programs?

Answer: NSF is the lead agency for Federal support of ground-based astronomy research. NASA programs in astronomy and astrophysics primarily provide observing facilities in space which can carry out observations not possible from the ground. Programs of the two agencies are well-coordinated to assure no duplication of effort. Long term planning is also coordinated via the decade reviews such as the National Academy of Sciences Field Committee Report "Astronomy and Astrophysics for the 1980s," which was jointly supported by NASA and the NSF. This report proposed a coherent plan for ground- and space-based astronomy research for the coming decade. NASA and the NSF are attempting to carry out the recommendations addressed to each, respectively and in coordination with each other.

ENGINEERING

Engineering is defined in the Random House Unabridged Dictionary as, "The art or science of making practical applications of the knowledge of pure sciences."

Your budget this year continues a trend of sharply increased emphasis on support for engineering.

Question: The National Science Foundation's unique role is doing basic research. Since engineering, by definition is the application of basic research, is not the movement toward engineering a move away from the Foundation's basic science mission?

Answer: The Random House definition covers part of the activities of engineering. In addition to utilizing the discoveries of science, engineers through basic research develop a science base for their fields. Basic research in engineering emphasizes man-made systems in much the same way that basic research in science emphasizes natural systems. Neither is exclusive of the other field, as there is a continuum and overlapping of activities. Many activities are technology-driven rather than science-driven, and technological and engineering advances frequently lead to the development of new scientific knowledge.

Many areas of engineering, such as design, manufacturing and computer engineering, lack a broad knowledge base, and are driven more by empirically-gained knowledge. The Foundation seeks to build classical research communities in these fields with commonly accepted research paradigms and to establish coherent, integrated bodies of knowledge and principles, which are needed for rapid technological advances.

Through the support of academic research, NSF also seeks to strengthen the engineering manpower base in emerging and critical fields of engineering, and to strengthen the linkage between the applications of engineering in industry and the research and teaching in our Nation's universities.

For the U.S. to maintain its economic vitality, it must have a strong engineering knowledge base and research infrastructure, one that can respond to new technological opportunities by having the resourcefulness to innovate, the basic knowledge to rationalize and the manpower pool to draw talent from. The Foundation is supporting the kind of fundamental, long-range research that has great potential to catalyze and expand the engineering knowledge and manpower base, thus creating an environment in which major technological advances can occur.

It has come to my attention that the Sacramento Peak Observatory may be slated for closing, or its operations significantly cut back, in fiscal 1986. I also understand the observatory has an excellent scientific reputation and houses a unique instrument, the Vacuum Tower Telescope. I am some what concerned that the scientific community has not had sufficient time to adequately evaluate the effects on the solar astronomy program, which may result from the closing of this facility.

Question: Are you planning an in-depth, scientific and technical study, by solar scientists to evaluate the closing of this facility? If so, I would like to be kept informed as to its deliberations; and if not, I would like to know on what basis you are going to make your decision.

Answer: A proposal to change the level of operations at Sacramento Peak Observatory (SPO) has been submitted to the Board of Directors of Association of Universities for Research in Astronomy (AURA), the consortium that operates the Observatory under contract from NSF, for their consideration. Following actions by the AURA Board, AURA must forward to NSF its requests for proposed changes to the FY 1985 program already approved by the Foundation.

The Foundation is planning a careful review of these proposed changes. The request from AURA will be considered by the NSF's Advisory Committee for Astronomical Sciences (ACAST) at its meeting May 6-7, 1985. This meeting will be held in Tucson, Arizona to facilitate in-depth discussion of this topic, which will be a major item on the agenda for the meeting. The ACAST will be supplemented with experts from the solar physics community for this discussion.

The Foundation may also solicit written reviews of the AURA request from the members of the affected communities.

The Foundation has notified the Air Force Office of Scientific Research, which provides some funds for support of SPO, that we expect changes to be proposed, which may include closing of SPO. The Air Force Geophysics Laboratory, which maintains a contingent of scientists at SPO has also been notified concerning the possible closure of SPO. The Astrophysics Division of the National Aeronautics and Space Administration (NASA) has also been informed.

NASA and the USAF will be requested to review the recommendations submitted to the Foundation. Appropriate officials of these agencies will be invited to provide their views and comments in time for consideration by the ACAST at their May meeting.

Advice from the ACAST meeting together with other opinions, solicited or unsolicited, from the astronomical community will be considered in arriving at the Foundation's response to AURA's proposal. The Foundation's response will be reviewed by an appropriate committee of the National Science Board.

As you can see, any decision to change the level of operations of a national user facility is made only after exhaustive discussions with all involved parties have taken place. We will certainly keep you informed on the progress of the current evaluation.

VETERANS ADMINISTRATION

STATEMENT OF HARRY N. WALTERS, ADMINISTRATOR

ACCOMPANIED BY:
PAUL T. BANNAI, CHIEF MEMORIAL AFFAIRS DIRECTOR
JOHN W. HAGAN, JR., ACTING CHIEF, BENEFITS DIRECTOR
DONALD L. IVERS, GENERAL COUNSEL
CONRAD R. HOFFMAN, DIRECTOR, OFFICE OF BUDGET AND FINANCE, CONTROLLER
EVERETT ALVAREZ, JR., DEPUTY ADMINISTRATOR
JOHN W. DITZLER, M.D., CHIEF MEDICAL DIRECTOR
SUSAN LIVINGSTONE, ASSOCIATE DEPUTY ADMINISTRATOR FOR LOGISTICS

OPENING REMARKS

Senator GARN. Next, I would like to invite Mr. Walters and his staff from the Veterans Administration to proceed to the table.

Mr. Walters, I am happy to welcome you back to the subcommittee again for your annual appearance. I would like to commend the entire VA system for the outstanding service the system is providing, as well as the excellent medical research that is being conducted within its facilities.

I am also sure that the VA system can be structured to be more efficient in these times of high budget deficit while still providing the level of service that has come to be expected of the Nation's largest medical care delivery system.

There are about 28 million veterans, 51.3 million family members of living veterans, and 2.2 million survivors of deceased veterans. Thus, 81.5 million, or about 35 percent, of the U.S. population are potential recipients of veterans benefits provided by the Federal Government.

VA's funding request of approximately $26.3 billion is composed of $15.6 billion in benefits, $9.4 billion in medical programs, $612 million in construction programs, and $752 million for general operating expenses. This request represents an increase of $259 million over the fiscal year 1985 appropriations level. The budget also assumes a decrease of 919 positions below the estimated fiscal year 1985 level.

PREPARED STATEMENTS

Mr. Walters, I would appreciate it if you would summarize your opening statement. Of course, I will be happy to include your full statement and that of your directors, in full, in the record.

[The statements follow:]

STATEMENT OF HARRY WALTERS, ADMINISTRATOR OF VETERANS AFFAIRS

Mr. Chairman and members of the committee, I am pleased to appear before you today to testify in support of the Veterans Administration's fiscal year 1986 budget. This budget will allow us to continue to serve our Nation's veterans well.

As you know, Mr. Chairman, this budget shows an effect of the President's emphasis on reducing the Federal deficit. However, you will find during this review of the budget, that the VA has fared very well in comparison to some other departments of Government.

The total budget authority request for 1986 is $27.1 billion which consists of an appropriation request of $26.3 billion, −$61.8 million for proposed legislation and an estimate of $851 million through permanent authorizations. Increases in benefits for service-disabled compensation and pension beneficiaries and funding increases in medical care are more than offset by the 5-percent reduction in 1986 pay, implementation of third-party reimbursements for medical insurance coverage, increased loan guaranty fees, and a reduction in construction funding.

Legislation is being proposed to eliminate medical care without regard to income levels for those veterans over 65 and make their eligibility the same as veterans under 65. This reform would restrict the use of the system by all nonexempt veterans whose income exceeds the eligibility level which will be twice the pension level.

These higher income veterans would not be eligible for VA health care until their out-of-pocket medical expenses exceeded certain amounts. These amounts would be an increasing percentage from 25 to 90 percent of the amount that the veteran's income exceeded the eligibility level. This eligibility level would be set at twice the VA pension income standard. In emergency and extraordinary circumstances, veterans could receive care in the VA medical system by making their out-of-pocket contributions direct to the VA for the medical care received. In rare and exceptional circumstances, the VA Administrator could waive the veteran's expected medical expense contribution.

We are also planning to build on the mission and goals which the department heads and I established shortly after I joined the VA. Agencywide we are beginning the pursuit of a cost-saving ADP and telecommunications modernization goal as a major element of our management goal. The thrust of that goal will be to provide better service to the veterans through the increased use of modern ADP and telecommunications technologies. I will be sharing with you over the next several months more detailed information about this goal and the objectives that support it.

I will now highlight the VA's request for major accounts.

COMPENSATION

The appropriation request for this account is $10.2 billion. This amount is based on an estimated caseload of 2.2 million veterans which is a slight decrease from 1985 and 335,000 survivors, a decrease of 4,100 from 1985. A rate increase of 4.1 percent, effective December 1, 1985, at a cost of $342.8 million, also is included under proposed legislation. A December 1, 1984, rate increase of $263.4 million is being met primarily with a supplemental appropriation request of $175 million. Lower caseloads in both compensation and pensions allow the remaining costs to be met with existing funding.

PENSIONS

The pensions caseload will continue to decrease in 1986. Current estimates indicate the veterans caseload will decrease by 34,000 to 676,000 while the survivors caseload will decrease by 64,000 to 711,000. However, total budget authority shows an increase of $26.6 million to $3.8 billion due to an anticipated automatic cost-of-living increase of 4.1 percent effective December 1, 1985.

BURIAL BENEFITS AND MISCELLANEOUS ASSISTANCE

A budget authority increase of $2.8 million to $136.8 million is requested. This increase reflects the higher mortality rate of the aging veteran population.

READJUSTMENT BENEFITS

An appropriation in excess of $1 billion is requested for 1986. This request, a decrease of $156 million from the 1985 request, shows the continued decrease of trainees as more veterans pass their 10-year delimiting date or attain their educational objectives. A 1985 supplemental appropriation of $44.2 million is requested to fund the 10-percent rate increase effective October 1, 1984.

LOAN GUARANTY

This request includes $404.6 million to help fund obligations of $1.91 billion. Estimated obligations for 1986 are $419 million less than the 1985 estimate. The Deficit Reduction Act of 1984 requires the VA to acquire properties under certain conditions. This act also raised the one-half percent loan origination fee to a 1 percent loan origination fee on all loans. Revenue from this loan origination fee is to be deposited into the Loan Guaranty Revolving Fund to offset required obligations.

The administration will request, under proposed legislation, an increase in this loan origination fee from the current 1 percent to 5 percent on both guaranteed and vendee (direct) loans. The vendee (direct) loan purchaser will have the option of paying the 5-percent loan origination fee or a 1-percent loan origination fee and a minimum of 5 percent down payment with a purchase of private mortgage insurance. If these initiatives are converted into public law, the fees will preclude the need for the $404.6 million budget authority request. This request clearly reflects the administration's policy to require those receiving Federal loan guarantees to pay for part of all of the expected Federal default liability on the guaranteed loans.

Legislation also will be proposed to repeal the current authority to establish the maximum interest rate and instead allow negotiated rates between borrowers and lenders.

GENERAL OPERATING EXPENSES

The budget request for general operating expenses is $749 million and 18,681 average employment for the operations of the Department of Veterans Benefits, the Department of Memorial Affairs, and the various staff functions of our central office.

On February 11, 1985, a meeting was held between the VA Administrator and the Deputy OMB Director. At that time it was agreed that VA would develop a plan for modernizing its entire operations and will be considering various efficiency alternatives, one of which will be DVB consolidation. This effort has just begun and, when it is completed, a decision will be made as to the best course of action to be taken concerning DVB.

The Department of Memorial Affairs shows a request of 1,161 FTEE which is a reduction of 57 below the 1985 level. This reduction will be achieved by contracting various activities at national cemeteries. It is expected that total interments will increase by 6 percent, gravesites maintained will increase by 2.5 percent, and headstone/marker applications processed will be 2.7 percent over 1985 levels.

In the general administration activity, 1986 funding and FTEE will be reduced below the 1985 estimates by $680,000 and 154 FTEE, respectively. The FTEE reductions will be achieved through improved productivity and efficiencies in operations which will not reduce services provided. To assist in this effort, $2 million is included for office automation. Within the data processing activity, several facilities will close with those functions consolidated at the primary data processing centers in Hines, IL, and Austin, TX. The closure of the St. Paul and Los Angeles data processing centers, and the Romney, WV, message switching center will result in average employment requirements being reduced by 113.

MEDICAL CARE

The medical care appropriation request for 1986 is $9.1 billion, an increase of $235.6 million over the 1985 level. Average employment is projected to increase by 199 over an adjusted 1985 employment level of 191,849. The number of inpatients treated is projected to increase by 3,211 to a level of 1.4 million, and outpatient medical visits will increase by 112,000 to a level of 18.8 million. The increased resources also will provide partial year activation resources for the replacement hospital at Portland, OR, replacement and modernization of clinical services at Albuquerque, NM, and expansion of clinical, outpatient and administrative facilities at Birmingham, AL. One new satellite outpatient clinic will be activated.

The 1986 request also provides for new or expanded initiatives in the areas of: the integrated hospital system, Occupational Safety and Health Program, and a physical fitness program for the disabled/handicapped.

In addition, legislation will be proposed to obtain reimbursement from third-party insurance carriers for the cost of medical care and treatment to non-service-connected veterans.

MEDICAL AND PROSTHETIC RESEARCH

The 1986 total request for medical and prosthetic research is $187.1 million and 4,348 FTEE. The 1986 requirement for the agent orange epidemiology study being conducted by the Center for Disease Control is $3.8 million. Research support will continue in the ongoing high-priority research programs in agent orange, aging, health of former prisoners of wars, alcoholism, health problems of female veterans, spinal cord injury, delayed stress disorders, cancer, preventive health, and prosthetic/sensory aids. Because of their high priority, no FTEE reduction is planned for prosthetic research and health services research.

MEDICAL ADMINISTRATION AND MISCELLANEOUS OPERATING EXPENSES

The 1986 request for this program is $55.9 million and 753 FTEE. These amounts reflect the effects of the 5-percent governmentwide pay reduction, the GS/GM 11-15 grade reduction excluding title 38 employees, a 10-percent administrative reduction, and the phasing out of the Health Professional Scholarship Program.

CONSTRUCTION

The 1986 request for the two construction appropriations totals $611.6 million. An additional $160 million, available from previous appropriations, will contribute toward a total program level of $771.6 million. Included is $712.9 million for medical facility projects, $18.9 million for the National Cemetery Program, $2.0 million for the Department of Veterans Benefits Regional Office Program, $2.0 million for the Office of Data Management and Telecommunications, $500,000 for the year-old emergency fund, and $35.3 million for general administration.

There are 33 projects in the major projects construction request. Initial construction funding is requested for Philadelphia, PA; funding for the main hospital building for Houston, TX; and renovations and replacement of buildings in Mountain Home, TN, also is requested. The major construction request for the National Cemetery Program is $12.5 million: $6.5 million is requested to provide for construction in Florida; and $6 million is requested for a land acquisition in northern California for a national cemetery. The construction program also continues to emphasize the correction of life safety and other code deficiencies. Two new nursing homes are scheduled for construction in Amarillo, TX, and Tucson, AZ.

This concludes my prepared statement, Mr. Chairman. My staff and I will be pleased to answer your questions regarding the 1986 budget estimates of the Veterans Administration.

STATEMENT OF JOHN W. HAGAN, ACTING CHIEF BENEFITS DIRECTOR, VETERANS ADMINISTRATION

Mr. Chairman and members of the subcommittee, I am pleased to present the Department of Veterans Benefits' fiscal year 1986 appropriations request. The Department administers an integrated program of veteran benefits consisting of compensation, pension, burial, reinstated survivor benefits, education, jobs training, vocational rehabilitation and counseling, loan guaranty, insurance, fiduciary and field examination, and veterans benefits' request for $15.6 billion represents 59.3 percent of the VA's approximately $26.3 billion in appropriation requirements.

Compensation, pensions, burial, and miscellaneous benefits are the largest segment of our budget. Our 1986 request for these benefits is $14,160,800,000. This amount is $7 million less than our 1985 level which includes a supplemental request of $175 million to fund projected increased payments to our beneficiaries. Again this year, we request that compensation, pensions, and burial benefits be appropriated as three separate accounts. And again, I hope that this matter will be resolved.

The 1986 appropriation request for compensation is $10,186,000,000. This request, when adjusted for the $175 million supplemental request and other funds transferred to compensation in 1985 is $36.5 million less and is based upon:

—A projected decrease of 20,000 compensation cases in 1986; and

—Average costs decreasing because of lower average degrees of disability and fewer number of beneficiaries per case.

The cost of the recently enacted Public Law 98-543, which increased compensation and clothing allowance rates by 3.2 percent, effective December 1, 1984, is estimated at $263.4 million in 1985 and $316.3 million in 1986. The proposed rate increase for 1986 is 4.1 percent Effective December 1, 1985. The cost of this increase is estimated at $342.8 million.

The appropriation request of $3,838,000,000 for pensions is $26.6 million greater than the 1985 amount when adjusted for the transfer of $195 million made in 1985 to compensation.

We expect a pension caseload decrease of 99,000 from the 1985 level of 1,486,000. However, average annual payments are expected to increase by $177, primarily because of the automatic cost-of-living provision under which the pension program operates. We estimate that increase to be 4.1 percent effective January 1, 1986, at a cost of $131.6 million.

The burial benefits and miscellaneous assistance portion of our appropriations encompasses a comprehensive Burial Benefit Program, several special payments categories, mortgage life insurance, and the Veterans Group Life Insurance Program. Due to an increase in veteran deaths and increased contributions by the VA to the Veterans Mortgage Insurance Program, the 1986 requirements are $2.8 million greater than those of 1985. The appropriation request for this category is $136,800,000.

To summarize, the 1986 requirements of the above benefit appropriations are only $7.1 million or five one-hundredths of 1 percent lower than 1985. This funding, however, will provide an average monthly compensation benefit of $331 for nearly 2.6 million veterans and their survivors. It will also provide nearly 1.4 million veterans and their survivors an average monthly pension income of $231.

Our $1,026,000,000 readjustment benefits appropriation request for 1986 is $156 million lower than 1985 which includes a supplemental request of $44.2 million. The supplemental funding, Mr. Chairman, is requested to help fund the 10 percent rate increase authorized by Public Law 98-543.

A reduction in the number of GI bill (ch. 34) trainees contributes to this decrease. It is expected that 82,500 fewer veterans and servicepersons will train in 1986 than in 1985. This decrease is attributable to a greater number of veterans who have either used their entitlement or have reached their 10 year delimiting date and fewer servicepersons eligible for chapter 34 benefits.

These funds will provide monthly education assistance payments to: 342,700 Vietnam era veterans and servicepersons; 28,400 disabled veterans in need of vocational rehabilitation; and 54,300 children and dependent spouses. Also provided for are 405 specially adapted housing grants, 650 automobile grants, and 6,600 automotive adaptive equipment items.

Public Law 98-525 established the new peacetime GI Bill Education Program for persons entering active duty during the period beginning on July 1, 1985, and ending on June 30, 1988, and who agree to have their military salary reduced $100 a month for their first 12 months of active duty. No education assistance is expected to be made to these veterans until 1987. This law also established an education program for certain members of the selected reserve. For those reservists who may become eligible in 1985, the Department of Defense will be transferring $100,000 to the VA in 1985 and $8.3 million in 1986 to make payments for these eligible trainees.

In fiscal year 1984, $152.1 million in education overpayments were established which represents a decrease from fiscal year 1983. The balance of education overpayments on hand has decreased from $582.9 million at the end of fiscal year 1983 to $548.2 million at the end of fiscal year 1984.

Internal Revenue Code section 61(A)(12) requires that all discharge of indebtedness over $600 be included in a taxpayers gross income. In order to comply with that requirement, our centralized accounts receivable system [CARS] was programmed to automatically track and report any discharge of indebtedness over $600 to Internal Revenue Service. In 1984, 1,958 cases with a value of $4.2 million were reported to the IRS.

Our 1986 requirement for the Loan Guaranty Program is $404.6 million to help fund more than $1.9 billion of obligations. While the deposit of loan origination fees into the loan guaranty revolving fund has helped reduce our funding request, it has not been sufficient to eliminate it. We will, therefore, request, under proposed legislation, an increase in the loan origination fee from 1 percent to 5 percent on both guaranteed and vendee (direct) loans. Purchasers of vendee (direct) loans, however, will have the option of paying the 5-percent fee or pay a 1-percent fee with a minimum 5-percent down payment and purchase private mortgage insurance. Enactment of these proposals will eliminate our 1986 appropriation request.

Legislation also will be proposed to repeal the authority to establish the maximum interest rate in favor of allowing negotiated rates between borrowers and lenders.

VA's insurance programs make what we feel are significant contributions by providing insurance protection for veterans, their families, and dependents. Since only one of the six Government-administered insurance programs is available to new enrollees, the total number of insured veterans is expected to decline. Also, as the average age of insured veterans rises, death and disability claims can be expected to rise. Four of our six insurance programs pay dividends. In calendar year 1985, more than 3.4 million veterans will share in a record $797.9 million in dividends.

Mr. Chairman, the funding that was authorized for the Jobs Training Program will provide, by the end of 1986, training opportunities to 33,900 veterans at a cost of $140.5 million. The remaining $9.5 million, of the $150 million appropriated, was used for veterans training under the post-delimiting date extension as authorized by Public Law 98-77.

The final area I would like to address today involves the Department's GOE budget request of $490,889,000. This is a reduction of $4,057,000 from 1985 and will support an average employment of 12,894, a reduction of 624 from 1985.

The 624 reduction in average employment is attributable to the proposed consolidation of adjudication, loan processing, and administrative activities into three locations. On February 11, 1985, a meeting was held between the VA Administrator and the Deputy OMB Director. At that time it was agreed that VA would develop a plan for modernizing its entire operations and will be considering various efficiency alternatives, one of which will be DVB consolidation. This effort has just begun and, when it is completed, a decision will be made as to the best course of action to be taken concerning DVB. The reduction in employment is principally responsible for the $13.4 million decline in payroll costs. The 1986 proposed 5-percent pay cut of $12.3 million was more than offset by the $12.9 million included in payroll to effect consolidation. Increases in rents, communications, utilities, travel, supplies, and equipment partially offset the payroll savings for a net decline of $4.1 million in 1986.

Mr. Chairman, this concludes my statement. We will be glad to discuss our budget with the subcommittee.

STATEMENT OF PAUL T. BANNAI, CHIEF MEMORIAL AFFAIRS DIRECTOR, VETERANS ADMINISTRATION

The Department of Memorial Affairs is responsible for three Veterans Administration missions: First, the operation and maintenance of the Veterans Administration national cemetery system; second, the procurement and shipment to destination of headstones and markers furnished upon application for veterans' graves in both national and private cemeteries; and third, the grant program for aid to States in establishing, expanding, or improving State veterans cemeteries.

The management structure within the Department of Memorial Affairs to supervise and control our assigned missions consists of a central office staff and three offices, presently located in Philadelphia, Atlanta, and Denver.

A total of 141 cemeterial installations are now included in the national cemetery system, of which 109 are national cemeteries and 32 are miscellaneous burial plots and monument sites. The 109 national cemeteries include the new regional cemetery at Indiantown Gap, PA, which opened in September 1982; the Quantico, VA National Cemetery which opened in May 1983; and the regional cemetery at Fort Custer, MI. VA took over operational control of the Fort Custer Cemetery on February 1, 1984. The post cemetery at Fort Richardson in Anchorage, AK, opened as a national cemetery in May 1984.

Resources are also included in 1986 for the initial staffing and equipment needs for the regional cemetery at Fort Mitchell, AL. This cemetery is scheduled to open in fall 1986.

Under the general operating expenses appropriation, we are requesting $44,269,000 in budget authority for cemeterial operations and maintenance. Some 64.5 percent or $28,547,000 of this is for salaries and other related benefits and will fund an average employment of 1,161. The other 35.5 percent or $15,722,000 will be used for equipment, supplies, fuel, contracts, and communications.

During 1986 we expect to accomplish 51,000 interments and maintain 1,621,000 occupied gravesites. In addition, our workload includes the processing of 308,000 applications for headstones and markers.

The 1,161 average employment we plan to fund in 1986 includes an average of 374 general schedule employees and 787 wage grade employees. We have computed the personnel requirements on the workload ratio of 1 employee per 170 interments and 1 employee to maintain 2,968 occupied gravesites. The 1,161 employment request represents a decrease of 57 positions under the 1985 level of 1,218. A total of 73 FTEE was reduced in anticipated savings from making better use of contracting for departmental activities at VA national cemeteries. The budget request includes increases in contractual services to support this effort. This reduction is partially offset by an increase of 16 FTEE to support the activities at both the Fort Mitchell and Bay Pines National Cemeteries.

The 1986 request for construction funds totals $18,900,000. With these funds, we will develop 13,000 gravesites and construct an administration building at Florida N/C as well as purchase land for a national cemetery in northern California. Included in the requested amount is $6,400,000 in construction minor funds to provide needed cemetery facility improvements.

The year 1986 will be our seventh year of operation of the State Cemetery Grant Program. Appropriated for 1985 was $5,000,000. A total of $3,000,000 is requested for 1986.

That briefly summarizes the 1986 budget request for the Department of Memorial Affairs. I will be glad to answer any questions you may have.

STATEMENT OF JOHN W. DITZLER, M.D., CHIEF MEDICAL DIRECTOR, DEPARTMENT OF MEDICINE AND SURGERY, VETERANS ADMINISTRATION

Mr. Chairman and members of the subcommittee, the Veterans Administration is committed to providing quality medical care to veterans both today and into the future. The Veterans Administration will be proposing legislation to amend title 38, U.S.C. to comprehensively reform medical care eligibility by establishing a means test for veterans of all ages, where applicable. This will enable us to concentrate our efforts and resources on those veterans with service-connected disabilities, additional special category veterans, and on non-service-connected veterans without resources to defray all or part of their health care expenses.

In addition, legislation will be proposed to effect reimbursement from third-party insurance carriers for the cost of medical care and treatment to veterans with non-service-connected disabilities. These collections will be used to reduce the amount shown for resources applicable to the VA, but will not reduce the appropriation request for the medical care account.

The 1986 budget was carefully formulated to insure that the very important goals of deficit reduction and providing timely, quality care to eligible beneficiaries could be achieved.

The 1986 medical care budget request provides for an increase of $235.6 million and 199 FTEE over the 1985 revised level. The $9,090,000,000 and 192,048 FTEE budget also reflects the governmentwide actions of a 5-percent pay decrease, a continuing reduction in the number of GS/GM 11-15's (exclusive of title 38 employees), and an increase in employee productivity. Patients treated are estimated to increase by 3,211 (1,680 in VA facilities) and outpatient visits should increase by 112,000. The 1985 estimate includes a rescission proposal of $10.3 million to reflect the Deficit Reduction Act of 1984 and a proposed supplemental of $72.5 million for increased 1985 pay costs. The 1985 average employment is now estimated at 191,849, 2,092 below the authorized ceiling. This level will, through better management of 1985 resources, provide an appropriately balanced program with efficient utilization of personnel that is sufficient to achieve 1985 workload objectives and facilitate the achievement of the 1986 FTEE level.

Under medical administration and miscellaneous operating expenses [MAMOE] resources have been reduced for the effect of the 5-percent governmentwide pay reduction, the GS/GM 11-15 grade reduction (exclusive of title 38 employees), a 10-percent administrative reduction, and the phasing out of the Health Professional Scholarship Program. The 1985 employment level is estimated at 837 FTEE, a level of 23 below the authorized ceiling to allow better management of 1985 and to facilitate the achievement of the 1986 employment level of 753.

For medical and prosthetic research, which also includes the 5-percent pay and GS/GM 11-15 reductions (excluding title 38 exemptions), the appropriation request is $187,080,000, a reduction of $5.3 million and 157 FTEE below the 1985 level.

This level includes $3.8 million for the continuing requirements of the centers for disease control [CDC] agent orange epidemiology study and provides for inflation adjusted continuation of the 1985 project levels for rehabilitation and health services research. The employment reduction will be applied to the medical research program and will affect only the lowest priority research.

Under grants for construction of State extended care facilities, the requested 1986 level is $22,000,000, a level which will allow progress in reducing backlog levels in this program.

We are requesting $500,000 for grants to the Republic of the Philippines in 1986, the same level as 1985. This grant supports the maintenance and upkeep of the Veterans Memorial Medical Center physical plant and facilities.

This concludes my opening statement, Mr. Chairman. I will be pleased to answer any questions you or members of the subcommittee may have.

ADMINISTRATOR'S REMARKS

Senator GARN. Please proceed.

Mr. WALTERS. Thank you, Mr. Chairman, and members of the committee. I am grateful for the opportunity to appear before you today to discuss the VA 1986 budget.

When I was confirmed as Administrator of Veterans Affairs, I said I would be the advocate for our Nation's veterans. In that regard, no budget can adequately repay our veterans for all they have done for America.

However, I, like the veterans the VA supports, realize that the Nation has a challenge confronting it—the deficit. Veterans have always been willing to share in solving America's problems so long as they were treated fairly in comparison to those who did not serve.

This year's budget does treat veterans fairly in relation to other Government activities. I believe that this fact demonstrates the importance that the President places on veterans and veterans benefits.

I have a brief summary of the budget, which you have already summarized for me, Mr. Chairman, so I won't bother you with that.

ADJUSTMENT OF MEDICAL CARE FOR OLDER VETERANS

I would like to highlight, though, that this budget contains proposed legislation to eliminate the requirement to provide medical care, without regard to income levels, for those veterans over 65 and to make their eligibility the same as veterans under 65. Exempted from this reform would be service-connected veterans and certain categories of other veterans. This reform would restrict the use of the medical system by all nonexempt veterans whose income exceeds the eligibility level, which is twice the VA pension level.

I believe this to be important legislation and ask your support in its passage. Need, not age, should be the critical factor in determining eligibility for non-service-connected veterans. Legislation is also proposed to obtain third-party reimbursements for the cost of medical care and treatment for veterans with non-service-connected disabilities. The VA already does this when it can.

In the construction appropriation request, $712 million is included for medical facility projects, $18.9 million for the National Cemetery Program, $2 million for DVB, $2 million for the Office of Data Management and Telecommunications, $500,000 for the year-old emergency fund, and $35.3 million for expenses of the Office of Construction.

Of the total program request of $771.6 million, $160 million is made available from prior appropriations. Of the 33 major projects, initial construction funding is included for the Philadelphia, PA, clinical addition and renovation, along with funding for the main hospital building for Houston, TX; funding for renovations and replacement of buildings for Mountain Home, TN, is also requested.

One other point I would like to make is that the outyear numbers for medical care are plugged numbers; they are not meaningful. National policy decisions must be reached. These decisions will affect the VA. Discussions leading to these decisions will be conducted in the sunlight, including the VA, veterans service organizations, Congress, and all other interested parties.

This briefly summarizes my opening remarks, Mr. Chairman. Of course, we would be pleased to answer any of your questions. But I would like to take this opportunity to wish you Godspeed in your quest in space. I believe it is scheduled for April 14.

Senator GARN. April 12 this time. I hope you are not right. [Laughter.]

Mr. WALTERS. April 12, hopefully.

Senator GARN. John Glenn told me the other day not to be discouraged yet, that I had only had 7 dates scheduled for mine and he had 11 before he finally went. I have no desire to exceed his record. [Laughter.]

Mr. WALTERS. Dr. Millie Ford is a research chemist with the VA and is also going to be an astronaut and is in training now. Dr. Ford is an Army reservist.

While you are in space, Mr. Chairman——

Senator GARN. A lot of people think I have been spaced out for years. [Laughter.]

Mr. WALTERS. I would like to make sure that you take a bumper sticker along. [Laughter.]

Senator LAUTENBERG. What does it say?

Senator GARN. I am taking a veteran along, myself. I am still a card-carrying member of the VFW and American Legion.

Senator LAUTENBERG. I didn't know whether it was a piece of advertisement as well. That one is OK. [Laughter.]

Senator GARN. I have been trying to get one, Frank, that says "Ski Utah" for the press conference.

Senator LAUTENBERG. I would go for that. [Laughter.]

WASHINGTON POST ARTICLE ON MEDICAL CARE

Senator GARN. The March 9 Washington Post article on VA medical care raised some questions regarding the definition of service-connected disabilities. Having long recognized that many facts I read in the paper and hear in the media are not correct, I would like you to clarify some of these issues.

First of all, how long does one have to be in the service to be considered a veteran?

Mr. WALTERS. Let me ask Dr. Ditzler to answer that.

Dr. DITZLER. Mr. Chairman, section 101, title 38, United States Code, defines the term "veteran" as one who has served in the active military forces. Now, section 3103(a) of title 38, enacted more recently, generally denies benefits, including medical care, to persons originally enlisting in the military after September 7, 1980, unless they have been in for a period of 2 years or for the length of service for which they had originally agreed to serve. Nonetheless, the interpretation can be made under certain cases that a veteran could have eligibility even if he or she had only 1 day of service, according to the law as it exists now.

Senator GARN. That would be an unusual circumstance.

Dr. DITZLER. It would be, but it could possibly be.

Senator GARN. Is it true that if an individual, while on active duty in the armed services, developed one of 40 diseases, from diabetes or peptic ulcers to cirrhosis of the liver, the VA will later consider that veteran as having a service-connected disability?

Dr. DITZLER. Mr. Chairman, if an individual while on active duty develops any disease, it is generally considered to be service connected, unless one can clearly establish that it existed prior to enlistment in the service.

Senator GARN. What logic is there behind that?

Senator LAUTENBERG. Mr. Chairman, would something like herpes be considered service connected?

Senator GARN. I don't know. [Laughter.]

Dr. DITZLER. Mr. Chairman, according to the law, section 101——

Senator GARN. I don't want to know anything about herpes. [Laughter.]

Senator LAUTENBERG. I think we ought to know whether we are paying for somebody's personal program.

Dr. DITZLER. According to the law, sir, section 101, title 38, United States Code, states that a disability is considered service connected if the disability was incurred or aggravated in the line of duty.

Senator GARN. What you are saying is there isn't necessarily any logic, but that is the way we wrote the law.

Dr. DITZLER. That is correct, sir.

Mr. WALTERS. There is a caveat to that. If we can show willful misconduct on the part of the veteran, then it would not be considered service connected.

Senator GARN. Obviously, Frank, baldness was not included in the service-connected disabilities. [Laughter.]

Senator LAUTENBERG. It is not disabling. It got you into space.

Senator GARN. Actually, it is very helpful for the electroencephalograms I have to put on myself. I put five electrodes on my head. If I had hair, I wouldn't be able to do that. You would have to shave little round spots to be able to accomplish that.

Senator LAUTENBERG. Just to be sure, your questioning is so interesting, I, too, am a veteran. Despite the youthful appearance, I served in World War II. [Laughter.] But any condition that develops during the period of service is considered service connected? Is there a list of those?

Dr. DITZLER. There is no list because any disease, or any other process, so long as it can't be established that it was present or historically present before entry into the service, is presumed to be service connected, except under willful misconduct.

Senator LAUTENBERG. That is very interesting.

Senator GARN. Would a permanently disabling injury occurring to an active duty individual in the U.S. military, while on leave or vacation, be considered a service-connected disability?

Dr. DITZLER. It would be, sir, unless, again, there was willful misconduct involved in the activity that created the problem.

Senator GARN. So it doesn't have to be in the performance of duty.

Dr. DITZLER. No, sir.

Senator LAUTENBERG. An exaggerated example, if someone were out recreationally and had a leg injury that was incapacitating, that would be considered service connected?

Dr. DITZLER. If he was on active duty and the activity which created the injury was not part of a misconduct arena, it would be.

Mr. WALTERS. Recently, Senator Lautenberg, some members of the Old Guard were drowned and some were injured in the Potomac River. They would be service connected for those disabilities. That was considered in the line of duty.

EVALUATION OF DVB WORKLOAD AND STAFFING

Senator GARN. The subcommittee directed that a report be prepared prior to September 1984 to "evaluate the workload and current staffing of the entire Department of Veterans Benefits." Although the subcommittee was notified, the report was delayed. No document has been forthcoming.

The Department is now proposing a decrease of 624 FTEE in fiscal year 1986. The subcommittee cannot understand how such an estimate can be made without a detailed understanding and evaluation of the existing workload and staffing.

It is imperative that this report be immediately provided if we are to adequately evaluate your budget proposals. We are not necessarily against it at this point. We just feel we need some basis on which to evaluate whether that is a proper number or not in your other budget proposals.

Can we have some estimate of when we will have this report?

Mr. WALTERS. The Arthur Young & Co. study is complete and it is now being staffed in our office. In the not too distant future we will be forwarding that study to you.

The study makes some recommendations. We have to implement the recommendations before we can give you the data that you require and that we require to make better decisions. It is going to take another 2 or 3 months to implement the recommendations of that study. I think Arthur Young & Co. is on the right track, though, from what I see now. Again, the report is not quite finalized.

I might add that in terms of the reduction of 624 FTEE, the proposal was built around a consolidation effort included in the passback from OMB, which the agency had not seen prior to the OMB passback. In a subsequent meeting with the Deputy Director of OMB, I was able to show, and convince him, that we need to modernize the distribution of the information system in DVB along with the Arthur Young & Co. study. We will then make our recommendations based on that, rather than consolidating up front with no apparent logic to support consolidation other than just to consolidate. I think that OMB understands this and we are now proceeding on that basis.

Senator GARN. But you think it will be 2 or 3 months before the report is available to the subcommittee?

Mr. WALTERS. The report will be available before that to you, Mr. Chairman, but the report will make a recommendation, which will take us another 3 months to implement, to determine what the work measurement system should be.

MEDICAL CARE STAFFING

Senator GARN. I understand.

The VA budget justification contains the estimate that the medical care account staffing in fiscal year 1985 will rise by 1,984 FTEE over the fiscal year 1984 level. This, however, is 2,092 FTEE below the level that the funding in the fiscal year 1985 appropriations bill—Public Law 98-371—specified.

The budget justification indicates a rise of 199 FTEE in fiscal year 1986 over the fiscal year 1985 estimate.

What would you expect to be the effect on staffing and medical services if the VA were to hire in the second half of fiscal year 1985 to permit a 2,000 FTEE rise in the jurisdictional average employment of medical care; and also if the funding provided in the fiscal year 1986 appropriation level for medical care was exactly at the budget justification level?

Mr. WALTERS. I would like to ask Dr. Ditzler to answer that question, Mr. Chairman.

Dr. DITZLER. Mr. Chairman, the 2,000 cumulative FTEE you referred to would require us to provide 4,000 FTEE beginning April 1. In terms of the dollars involved, it would necessitate, at the present level of funding, pulling at least $50 million from equipment and from all other accounts in order to fund those individuals.

This, we believe, would have a deleterious effect in pulling money from such accounts as drugs and other supplies which are equally important in maintaining the workload. So that, ironically, by leaving more individuals on duty, we might even suffer a lesser workload because part of the workload involves prescriptions and other support for patient care.

Senator GARN. Thank you.

[CLERK'S NOTE: The Veterans Administration has subsequently amended its testimony to state that if the additional employment support was provided in 1985 and not in 1986, the VA would be in a position of having to lay off the 4,000 FTEE at the end of fiscal year 1985. This would be very disruptive to operations and would have an adverse effect on patient care.]

SOUTH JERSEY OUTPATIENT CLINIC

Senator GARN. Senator Lautenberg?

Senator LAUTENBERG. Thanks, Mr. Chairman.

Mr. Walters, it is a pleasure to have the chance to talk to you.

One out of seven of our citizens in New Jersey is a veteran, I am told. We have a great interest in veterans programs and recognize the contribution that have been made by our Nation's veterans.

We have some, as I guess is the case throughout the country, serious problems in being able to deliver medical services adequately to the veteran population. In particular, South Jersey has a serious problem. I think you are aware of that. Medical service delivery is just inadequate in that area. The nearest medical facilities for the South Jersey veterans who need it are roughly 1½ to 2 hours away from veterans living in that area. They have to go to the northern part of the State. As small as New Jersey is, that is a pretty good trip.

The problem is growing daily because more and more people, including veterans and their families, are locating in the southern part of our State. We are going to have to do something and do it soon.

As you know, the medical district includes Delaware, parts of Pennsylvania and Maryland, as well as New Jersey. South Jersey has been identified as the most underserved area in that district. In fact, the district has recommended an outpatient clinic be established in the South Jersey area.

Is this familiar to you?

Mr. WALTERS. Yes, sir.

Senator LAUTENBERG. I haven't said anything wrong so far, so far as you see it.

I and other members of the New Jersey delegation wrote in January to urge that this facility be included in the fiscal year 1986 budget. You indicated at the time that the district's proposal was still under review. Can you tell me the status of that review now, please?

Mr. WALTERS. Obviously it did not make the 1986 budget, Senator Lautenberg. I am going to ask Dr. Ditzler to answer the question precisely as to where it is right now.

Dr. DITZLER. Senator, we would be looking to include it in the 1987 budget at this point in time. The medical district did recommend that there be an outpatient clinic facility in southern Jersey. Right now we have before us about 15 other requests for inclusion in the 1987 budget for outpatient clinics. That clinic is one of those under consideration.

Senator LAUTENBERG. You agree, do you not, Dr. Ditzler, that that is an underserved community in terms of the numbers of people that are there and who need attention based on the criteria that are established?

Dr. DITZLER. Not knowing too much in detail about the area myself, I do know that the people who come from the area, which involves the medical district planning process in that area, have recommended that a clinic be included as one of our priorities.

OUTPATIENT CLINIC METHODOLOGY

Senator LAUTENBERG. Certainly they did it based on the need, not based on the politics or anything else.

You have a methodology for assessing proposals for outpatient clinics. Is there a minimum number of visits required to justify such a facility?

Are these questions, Mr. Walters, to be addressed to Dr. Ditzler in this case?

Mr. WALTERS. Yes, sir. I think that the medical process, as part of the Department of Medicine and Surgery, is part of the planning process for the future. These questions are very properly directed to Dr. Ditzler.

Senator LAUTENBERG. Fine, whoever is most convenient. What is that number?

Dr. DITZLER. Well, it depends on the area and the geographic location. The minimum number could be less if we are talking about the middle of Montana or one of our less——

Senator LAUTENBERG [interposing]. Less densely populated areas.

Dr. DITZLER. Yes. But certainly for the New Jersey area the criteria would be met.

Senator LAUTENBERG. I think the yardstick number, which I was interested in getting on the record, is 15,000. Does that sound reasonable?

Dr. DITZLER. That is correct, sir.

Senator LAUTENBERG. The five counties in South Jersey—Ocean, Monmouth, Burlington, Mercer, and Camden Counties—make up the primary service area of the proposed outpatient facility. This was in 1982. There were almost 56,000 visits coming from that area alone.

So the case I think is made if we simply use the numbers compared to the requirement.

We just had a little discussion on service-connected ailments. Are we talking about service-connected ailments defined as you described them, anything that occurs while in service?

Dr. DITZLER. That has to be a requirement, to be service connected, that is correct.

Senator LAUTENBERG. The conditions do qualify as service connected, the array of things we said, that anything one contracted——

Dr. DITZLER. If it is clearly documented that it occurred during that service.

Senator LAUTENBERG. So the evaluation system does give some weight to service-connected ailments, correct?

Dr. DITZLER. That is correct.

Senator LAUTENBERG. I can tell you this, that our information says that in 1982, 40,000 cases, 41 percent of all the service required were service connected. That rate is very, very high. The veteran population in the area is 230,000, in the area we are talking about. I have seen projections based on fairly conservative estimates of population growth showing that by 1990, the South Jersey area could be meeting the minimum criteria for two outpatient clinics. I would suggest that that would then call for building a full service medical center capable of meeting this need.

Is that something that sounds logical?

Mr. WALTERS. It doesn't surprise me you would talk about it Senator Lautenberg. [Laughter.]

Senator GARN. Before you proceed, if I could interrupt, I just received a telephone call that I have a problem that I have to go take care of. I would appreciate it, Senator Lautenberg, if you would go ahead with your questioning as long as you wish and then close out the hearing for me.

I am sorry, Harry, to have to do that to you. You are probably not sorry because I have a long list of questions I will submit, more than 30 pages of detailed questions for your response in writing. I was not going to ask all of them orally. But I was particularly interested in the sizing of hospitals, your priority listing report, and an update on the famous San Francisco parking garage that we have been talking about for years. I tell you that so you will feel glad that I am leaving. [Laughter.]

But I do apologize for that and appreciate Senator Lautenberg taking over for me. We will submit those questions to you for your response in writing.

Mr. WALTERS. Thank you, Mr. Chairman. Godspeed.

Senator GARN. Thank you very much. This time I hope we go. [Laughter.]

Senator LAUTENBERG. We want you back, too, it is not just going; it is coming back.

Senator GARN. Thanks.

DVB REORGANIZATION

Senator LAUTENBERG [presiding]. Mr. Walters, we won't be too long, but there are some things that are very important for me to review with you and your colleagues here.

The impact of the proposed reorganization of the Department for Veterans Benefits is the focus for these questions. In your remarks you say the budget states that the VA will consolidate some of the DVB facilities. This may happen, but we cannot tell at this time. An effort to develop a plan for modernization of DVB activities has just begun. You say that in your statement.

Mr. WALTERS. Yes, sir.

Senator LAUTENBERG. Why then, Mr. Walters, did you notify the committee of a planned reorganization and consolidation of field office functions of the Department of Veterans Benefits earlier this month?

Mr. WALTERS. Senator, the consolidation effort, as I mentioned, is the OMB effort through the passback. We had no way of justifying that plan without an accompanying modernization proposal. I had already embarked on a rather familiar modernization goal in the Veterans Administration through all of the three departments and I was able to convince OMB that modernization should drive whatever efficiency efforts we are able to get out of the modernization, period. They have signed up for this, and this modernization goal is now being planned and implemented in the agency. We will have something more definitive to talk about by midyear.

Senator LAUTENBERG. That is a functional objective. It is not one that is designed to in any way reduce the services, benefits, et cetera.

Mr. WALTERS. No. As a matter of fact, as part of our modernization goal, Senator Lautenberg, I have insisted that the building block be the veteran. For a corporation, the building block would be the customer. The veteran should be our building block, so that the things we do will enable us to deliver better benefits to the veteran.

As I have commented before, which makes some of our people in DVB cringe, but I want to make sure I am very clear, the information distribution network in the Department of Veterans Benefits in the Veterans Administration is somewhere about where Sears and Roebuck was about 25 years ago; it needs to be modernized. This is no reflection on the people, but a reflection of government and the agency presently not having a modern technology base.

I know your background. I think you have some insight on that.

Senator LAUTENBERG. I don't know whether you want the VA to be a full-service company, including financial planning and so forth. That is what Sears is. The analogy, I assume, was designed to portray the modernization of a company and not the expansion of the services.

Mr. WALTERS. That is correct. I made the analogy to illustrate that, 25 years ago, you could have had a Sears and Roebuck card issued in Miami, which you may or may not have been able to use in San Francisco because the distribution process and communications process wasn't set up to handle it.

Senator LAUTENBERG. You have indicated that you want to consolidate staff functions in the DVB. This involves some reduction of VA employment in every State. You have not provided Congress with a plan for how this will be done. If you make these changes after the appropriations bill is passed, do you have the legal authority to consolidate these offices without congressional approval?

Mr. WALTERS. No, we don't. As Peter Grace is known to point out quite often on his radio shows, we can't move three people without asking the permission of Congress. In fact, he is correct. According to the law, Congress does have the final authority on that.

Senator LAUTENBERG. I just wanted to verify that and confirm what Mr. Grace said. That is an important criteria.

NEW JERSEY STATE VETERANS CEMETERY

You know that the State of New Jersey plans to open a new State veterans cemetery later this year. I understand the plan calls for the VA to provide matching funds for land acquisition and other costs. Have you approved the State plan for funding at this point?

Mr. WALTERS. Sir, I would like to ask our Director of Memorial Affairs, Mr. Paul Bannai, to answer that question for you.

Mr. BANNAI. Senator Lautenberg, there was $1.5 million appropriated with matching funds of an equal amount from the State of New Jersey. The Harrington site near Clinton is the first increment, which will be 19.6 acres of the 184 acres.

I understand that the ground has not been broken. I will be up there next week to look at the site. But I think that everything is ready. I anticipate that it will be on schedule and that we will now have a good cemetery to replace the two in New Jersey that have been closed.

Senator LAUTENBERG. Right, they have been closed. Will this one take care of projected requirements? We are talking about a cemetery that will accommodate 110,000 burials, I think.

Mr. BANNAI. Yes; at the minimum.

Senator LAUTENBERG. The projected requirements, future requirements, have we anticipated those adequately?

Mr. BANNAI. I believe so. Out of the 184 acres, most of it is usable land, I understand, very level land. I think you have more than an adequate amount to take care of all the needs of New Jersey, not foreseeing any other conflict in the near future.

HUNGER AMONG HOMELESS VETERANS

Senator LAUTENBERG. The President's Task Force on Hunger in its January 1984 report stated, "A disturbingly large portion of the homeless, perhaps one-third, are veterans."

Mr. Walters, what steps has the VA taken in response to this?

Mr. WALTERS. We are a part of the task force, Senator Lautenberg. The numbers which are being quoted concerning the number of the homeless, and the percentage of those that are veterans, are quite controversial. No one is able to support or deny the numbers. I have met with Mitch Snyder recently here in Washington, DC, as well as with the service organizations—Disabled Americans, Veterans of Foreign Wars, American Legion, and several others. He informed me that the numbers being quoted represent a numbers game. We just don't know.

Having said that, we asked Mr. Snyder to serve as a liaison between the VA and the homeless veteran where he exists, as it is very difficult to make and keep contact with a homeless veteran. The communications process has been very difficult.

Senator LAUTENBERG. Right. Even if the numbers are not precise, would it be fair to say that since veterans represent a pretty significant portion of our population generally, that there has to be a good sized number out there in the homeless group?

Mr. WALTERS. Well, I tell you, it could be a good sized number. I would like to state for the record, a piece of data which is not very well known, the fact that the Vietnam veterans in America are more heavily employed than the general population. Yet, if you read the media presentation of the Vietnam veteran, you would think he would be sort of down and out.

So I am not so sure what the percentage of the homeless veterans may be, but I think we can assume there may be homeless veterans.

DEINSTITUTIONALIZING MENTAL PATIENTS

Senator LAUTENBERG. There is a developing consensus that says that the deinstitutionalization of mental patients has increased the homeless population. Has the VA either done a followup study or a representative sample of veterans released from VA psychiatric care to determine what percentage, if any, are homeless? Have you looked into that?

Mr. WALTERS. I don't know. Perhaps Dr. Ditzler could shed some light on that.

Dr. DITZLER. Not with the specificity that you referred to. But we do have patients who drop out of long-term care programs, and whether they are being cared for in the private sector or not is not known to us as they are not coming back.

Mr. WALTERS. I should note, Senator Lautenberg, that the VA does reach out to homeless veterans throughout the country in our regional offices. We do make contact with shelters across the country. The veteran who recently died outside the White House was on our compensation rolls and was receiving almost $500 a month. We reached out to him in 1980.

Senator LAUTENBERG. It is hard to communicate that message, I know, because they are not in the traditional communications network. However, it would be a service to the veterans and to society generally if we could try to get that message out and make known that these services are available.

Dr. Ditzler, if we could in any way find out what is happening to the deinstitutionalized psychiatrically treated person——

Dr. DITZLER. If I might say so, Senator, one of the spotlights that is frequently focused on the Veterans Administration concerns increasing lengths of stay. Yet, it is in the area of long-term care of the psychiatric patient that we create our longer lengths of stay.

I would argue that the VA is being extremely humanitarian and is greatly concerned that these patients do not fall through the cracks of society. However, we are frequently charged with keeping people in hospitals too long.

Senator LAUTENBERG. The only way to win is to do your job conscientiously, as you indicated in the earlier part of your remarks. That is, we have an obligation to the veterans as a nation, and the best way to do it is to see they know there is contact, that there is a place, there is a community that cares about them.

Mr. WALTERS. Yes, sir.

Senator LAUTENBERG. I appreciate your obvious interest in these things.

WHITE RIVER JUNCTION RESEARCH AND EDUCATION PROJECT

For my colleague from Vermont, Senator Leahy, there is a question he wanted to ask Mr. Walters. It is as follows. It is his understanding that the Office of Management and Budget refused to allow any expansionary projects in 1986 except those listed on page 66 of the budget brief. On page 67 of the budget brief you request funds for a parking garage in Durham, NC, and Syracuse, NY. Both of those are new structures.

Why are these facilities which concern parking garages being funded by an agency functioning from a decrepit quonset hut in Vermont that is not being funded?

Mr. WALTERS. I will ask Mrs. Livingstone to respond to that question, Senator.

Ms. LIVINGSTONE. Senator, you are quite correct. The fiscal year 1986 budget does contain two parking structure projects. We were not funded for the research and education addition at White River Junction. This was consistent with guidance we received from the OMB. The two parking structures were perceived to be existing deficiencies. There has been a long-standing parking shortage at both of those facilities.

Clearly, from the perspective of the VA, the White River Junction project is also a high priority and we hope to be able to move forward with that in 1987.

Senator LAUTENBERG. But there is nothing planned for that in the fiscal year 1986 budget?

Mr. WALTERS. No, sir.

Senator LAUTENBERG. Is it a quonset hut up there?

Ms. LIVINGSTONE. I understand, from having spoken with the Chief of Staff, that it is very close to being one, if not exactly so.

Senator LAUTENBERG. It is a wonderful place to visit. I know White River Junction. But doing that kind of work in that type of facility seems inadequate.

I thank you all. As chairman, I have the responsibility of closing out this subcommittee meeting.

SUBMITTED QUESTIONS

[The following questions were not asked at the hearing but were submitted for response for the record:]

QUESTIONS SUBMITTED BY SENATOR GARN

PRIORITY RANKING OF CONSTRUCTION PROJECTS

Question: For three years, this committee has been suggesting that the VA develop a prioritization system to take the politics out of the VA major construction projects. A report was due us on this topic March 15, 1985. Why did we not receive it? When will we receive it?

Answer. The report has now been completed and will be submitted through the Office of Management and Budget in the near future. Upon OMB's approval, the report will be forwarded to your committee.

PRIORITY RANKING OF CONSTRUCTION PROJECTS

Question: Two years ago, you said that MEDIPP will enable you to validate what your real needs are, notwithstanding the forces of politics. The latest VA five year medical facility construction Plan dated June 1984 contains a list of the ten medical centers judged most in need of construction. Did you use MEDIPP as the primary source for identifying the facilities that would appear on this list?

Answer: In identifying the facilities that would appear on the "List of Ten", many evaluative factors were applied to medical centers where the magnitude of construction work required to correct deficiencies would result in a recommended strategy of major renovation or replacement. These factors include "primary factors" (demonstrated need based upon demographic analyses of current and projected workloads; fire/safety deficiencies; space and functional deficiencies; patient privacy/handicapped access; and the medical delivery role of the facility) and "secondary factors" (age and condition of building shell and site utilities; energy conservation; laundry, boiler and warehouse capacities/deficiencies). The combination of these factors resulted in the identification of the medical center(s) considered to be, overall, the most deficient. Although MEDIPP forms the basis for the demographic analyses of current and projected workloads and the identification of medical program needs as they relate to construction, it is only one of the factors used to determine which facilities would be on the List of Ten.

PRIORITY RANKING OF CONSTRUCTION PROJECTS

Question: Two years ago, you said that MEDIPP will enable you to validate what your real needs are, notwithstanding the forces of politics. The latest VA five year medical facility construction Plan dated June 1984 contains a list of the ten medical centers judged most in need of construction. Why did your FY 1986 budget justification not follow this list in priority order?

Answer: Although medical centers on the "List of Ten" are arranged in the order in which they have been added to the bottom of the list in recent years, the various elements of the planning and design process, along with other unforseeable contingencies, cause each project to follow varying timeframes as they move toward a position where the VA is ready to request construction funding. The inclusion of the Houston, Mountain Home and Philadelphia projects in the FY 1986 budget request is consistent with this process and the availability of FY 1986 funding in the replacement/modernization category.

LOAN GUARANTY PROGRAM

Question: Your default analysis indicates that there are almost seven vendee loan delinquencies for each loan delinquency. Why is this?

Answer: While the VA ordinarily applies the same credit underwriting standards in vendee loans as in guaranteed and direct loans, there are cases where higher risks are qualified in order to expedite the sale of properties on hand. While the approval of these risks does lead to a higher incidence of defaults, this must be weighed against the risks of holding a property for longer periods of time, subject to vandalism, property deterioration and additional carrying costs.

Question: The Congressional Budget Office estimated that the increase in the loan fee would cause a 20 percent drop off in the level of loan applications. Do you agree with this estimate?

Answer: We do not know the basis for the CBO estimate. The VA's FY1986 budget estimates that there would be no reduction in loan originations due to the increase in the funding fee. Veterans will have the option of financing the fee over the life of the loan. This would increase the monthly payment by approximately $29 on an average loan of $67,900.

Question: What would be the effect on the program if $200 million were appropriated instead of the $404.6 million requested?

Answer: An appropriation of $200 million for FY1986, without an increase in the funding fee, would not provide sufficient funding for the program. Sometime during March or April of 1986 the unobligated balance of the Loan Guaranty Revolving Fund would become critically low. The VA would be unable to honor its commitments to lenders as well as fund ongoing property management costs until additional funds could be appropriated by Congress.

Question: If the change in the loan rate to the market rate and the increase in the fees is enacted, won't the population who still try to get VA loans by borrowing the money for the five percent fee be the population who can't get a loan through any other means and thus be the most likely to default?

Answer: The change to the market rate and increase in funding fee should not seriously change the population interested in obtaining VA home loans. The program will still be attractive because of its basic features, i.e., no money down, fully assumable loans and no prepayment penalty. Additionally, under this proposal, the veteran-buyer, the seller and the lender can negotiate as to what the interest rate will be and who will pay some or all of any discount points. Thus a veteran should have more homes to choose from and the transaction can be tailored to fit the needs and circumstances of the parties involved. Because we have no experience with 105 percent loan-to-value ratio loans, we are not sure what impact these type of loans would have on foreclosure rates.

BALTIMORE HOSPITAL

Question: Senate Report 98-634 providing for a continuing appropriations for FY 85 directed the VA to perform a study evaluating the cost and the benefits of building a new hospital in Baltimore, Maryland and closing an existing facility or two other options involving refurbishing existing facilities. This was to be delivered to the subcommittee prior to April 1, 1985. There is only one remaining work day prior to April 1, 1985 and we have not seen or heard about the report. What is the status of the study?

Answer: The study has been completed and is currently undergoing executive review. It will be forwarded to Congress in the very near future.

BALTIMORE HOSPITAL

Question: Senate Report 98-634 providing for a continuing appropriations for FY 85 directed the VA to perform a study evaluating the cost and the benefits of building a new hospital in Baltimore, Maryland and closing an existing facility or two other options involving refurbishing existing facilities. This was to be delivered to the subcommittee prior to April 1, 1985. There is only one remaining work day prior to April 1, 1985 and we have not seen or heard about the report. Can you provide us with some idea of the recommendations that will be forthcoming?

Answer: The three options recommended by Congress have been evaluated and are included in the study. Since a final decision has not been reached on the recommended option, it would be premature to provide the recommendation at this time.

BALTIMORE HOSPITAL

Question: Senate Report 98-634 providing for a continuing appropriations for FY 85 directed the VA to perform a study evaluating the cost and the benefits of building a new hospital in Baltimore, Maryland and closing an existing facility or two other options involving refurbishing existing facilities. This was to be delivered to the subcommittee prior to April 1, 1985. There is only one remaining work day prior to April 1, 1985 and we have not seen or heard about the report. Can the working drawings previously prepared for this project be used without updating, should the new construction alternative be recommended?

Answer: The working drawings previously prepared for this project will require updating.

INTERMEDIATE CARE BEDS

Question: The October 29, 1984, Semiannual Report of the Inspector General indicates a study was done at five VA Medical Centers to evaluate treatment of 1,331 intermediate medical care patients. Their report concluded that as much as "$192 million could be redirected annually to other medical programs by appropriate placement of intermediate care patients in less costly care environments.

Do you agree with the findings?

Answer: It is difficult to estimate the savings which might be realized as a result of placement of intermediate care patients in alternative, less costly environments. The appropriate utilization of hospital beds could result in some savings. It is anticipated that there will be a net reduction of hospital beds overall which represents a potential savings. An increased cost will be associated with the need for additional resources in an expanded nursing home care program treating a higher proportion of severely disabled and totally dependent patients. In addition, the development of a more focused and clinically effective program of rehabilitation, convalescence, and outplacement in the proposed extended hospital care section will also require resources. An integral part of the intermediate care proposal which has yet to be addressed is the issue surrounding long term psychiatric care. Final estimates of bed section size, staff composition, and cost have yet to be determined. It is reasonable to assume that the task force working on the proposal will complete its work within three months. At that time, the Department of Medicine and Surgery could conduct a more specific assessment of the cost savings estimate contained in the Semiannual Report of the Inspector General.

INTERMEDIATE CARE BEDS

Question: The report suggests that as many as 7,171 patients receiving services in one of the intermediate care wards located at 69 of the 172 VA hospitals might be treated as well in a VA nursing home or in a local community nursing home. Since this represents almost eight out of ten VA intermediate care patients, the implications are far reaching.

Why are you still planning on providing beds for large numbers of intermediate care patients in the three proposed new replacement and modernization projects?

Answer: The three projects were planned using the VA/GAO bed sizing model negotiated between these two agencies under a Congressional mandate. In projecting the future need for medical beds in both acute and intermediate levels, the model automatically allocates, on the basis of past experience, acute medical days of care to the intermediate bed section.

A VA Central Office Intermediate Care Task Force has been engaged in a definitive study of the issues surrounding acute and intermediate care bed sections and has made a series of recommendations to the Chief Medical Director. These recommendations, including such things as the redesignation of certain acute and intermediate care beds based on the level of care currently provided in those beds, have been approved in principle.

The task force is currently developing appropriate modifications of the bed-sizing model to project future bed needs. After an appropriate analysis of these data, program guidance based on this information will be published as part of the Medical District Initiated Program Planning (MEDIPP) process, and a phased redesignation of beds and levels of care will take place. The accomplishment of this task should reduce criticisms directed at utilization of hospital beds in the VA system.

ADVANCE PLANNING FUNDS

Question: Advance Planning Funds are provided to do design concepts, preliminary drawings and cost definition in order to develop future construction projects. These funds are expected to be utilized over three fiscal years. The 28 million in FY 84 should be expended by the end of FY 86. Your budget justification indicates you will have about $4.8 million unobligated of the FY 84 advanced planning fund at the end of FY 86. In addition to this, you have already completed the advanced design for an extremely large number of projects that you were asking major construction funding for in FY 86, but were eliminated from your final budget justification sent to Congress. Recognizing these two facts, what rationale can you possible have to justify the request for $19 million in the FY 86 budget request?

Answer: Funds requested for the Advance Planning Fund in FY 1986 are to support projects that will be ready for consideration for inclusion in the budget request in FY 1989. In order to maintain acceptable facilities and provide for quality medical care, the Advance Planning Fund request for FY 1986 is necessary to support our future efforts.

DELEGATION

Question: You have delegated the authority to manage 21 major construction projects in FY 85 to the respective medical center directors. This committee had written you in November of 1984 expressing its concern with the magnitude of the effort proposed for FY 85 as well as the level of oversight the VA would be able to exercise over each project. We have not received a detailed reply indicating that you have reduced the number of delegated projects nor advising us of the exact control techniques you intend to implement for FY 85. How many delegated projects do you currently envision for FY 86?

Answer: Seventeen projects are approved to be delegated to the medical centers for FY 1986.

DELEGATION

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Answer: We do intend to supplement the medical center staffs with resident engineers and clerical assistance during the construction phase. In addition, Procurement and Supply has agreed to provide training for contracting officers, where necessary, and will supply technical guidance and reviews. The Office of Construction will have a representative on hand during contract negotiations, they will review drawings, and make periodic inspections during construction. Procedures provide for the Office of Construction to develop the Architect/Engineer package and there will be a central office review of the Invitation to Bid. Monthly Progress Reports will keep us informed if any problems arise.

Complete procedures have been developed which permit considerable latitude on the part of the Medical Center Directors to call upon the Office of Construction for heavy contracting assistance during both design and construction depending upon the capabilities of the individual Medical Centers.

Two specific training seminars are in development for the station engineers and procurement staff to teach the current network programming systems (CPM) required to control contractor payments and time of performance to minimize claims which are frequently experienced on larger projects.

NORTHERN CALIFORNIA

Question: The statement provided by the Director of the Department of Memorial Affairs indicates the request in FY 86 for $18.9 million in construction funds. Specifically, $6 million of major construction funding is requested to purchase land in Northern California in the general vicinity of San Francisco for new national cemetery. I am told the area selected is an industrial site.

Would you please describe the site and what would surround the selected site?

I have also been told that there is an offer to provide land for the national cemetery at no cost. This would be at a more remote rural location. Would you please comment on this option which we have not heard described?

Why should we not opt to save the $6 million?

Answer: The area of land preferred by the Veterans Administration is located at the Parks Reserve Forces Training Area (Camp Parks) in Alameda County. The site consists of 150 acres topographically suited to cemeterial purposes, and is currently owned by the Department of the Army. The Army has determined that this land is excess to their needs and it has been offered to the VA for development as a national cemetery site. The area surrounding the site is being developed as an industrial-transportation park, near major roads and public transportation.

The other site which has been reviewed and considered by the Veterans Administration is situated on approximately 400 acres in Merced County. The land is being offered to the VA thru a donation, and therefore would not require funds for land purchase.

Studies done by the VA have consistently shown that veterans and their families are far more likely to use a national cemetery when it is located within a 50 mile radius of home. Beyond that 50-mile radius, participation drops off sharply. It has been estimated that approximately 529,530 veterans live within 50 miles of the Merced County site as compared to 869,370 veterans within 50 miles of the Alameda County site. Proximity to centers of veteran population is a serious consideration in evaluating any new national cemetery's potential effectiveness. The Department of Memorial Affairs' primary goal in establishing national cemeteries is to locate them where they will cost-effectively serve as many veterans as possible. It is for this reason that the Department of Memorial Affairs supports the development of a national cemetery in Alameda County.

MAJOR CONSTRUCTION

Question: The Appropriations Subcommittee has previously informed the VA that it did not intend to incrementally fund the construction of projects in the VA's major construction account. This year, you are asking us to do this by requesting $190 million of the $226.8 million Houston VA project and $12 million of the $110.4 million Philadelphia VA project. What will be left to be completed at each location if the funds requested are appropriated?

Answer: The $36.8 million left in the Houston project is for demolition, site work, to include landscaping, sidewalks, roads, and parking, and Renovate building 206 (recreation). The entire Philadelphia project, with the exception of the Nursing Home Care Unit, connecting bridge and surface parking for Nursing Home Care Unit, will be left to be completed.

MAJOR CONSTRUCTION

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Answer: Yes. Both projects would be able to stand alone. The main hospital building at Houston could function effectively, however, access by patients and staff would be significantly compromised until the completion of parking, roads, and sidewalks included in Phase 2.

MAJOR CONSTRUCTION

Question: The VA's FY 85 prioritized list of medical centers most in need of major construction funding indicates that the Houston, Texas and Mountain Home, Tennessee replacement and modernization projects are ranked first and second for construction funding in FY 86. The project ranked third for FY 86 is Augusta, Georgia. Why was partial funding for the Philadelphia project included in your FY 86 budget request and Augusta excluded?

Answer: After Executive Review, the monies allocated in the Replacement/Modernization category were insufficient to fully fund three major projects. It was only possible to fund the Nursing Home Care Unit portion of the Philadelphia project. It was not possible to fully fund the $90 million required for construction of the Augusta project.

MAJOR CONSTRUCTION

Question: The budget of the U.S. on page 5-138 indicates that in FY 86 and FY 87 "Construction funds are proposed for four large hospital projects in Mountain Home, Tennessee; Houston, Texas; Philadelphia, Pennsylvania; and Augusta, Georgia." How do you interpret this statement in relation to new replacement and modernization projects?

Answer: We have previously received design funding for all of these hospitals. Since the FY 1986 budget proposal could only accommodate construction funding for Mountain Home, and part of Houston and Philadelphia, the remaining construction monies would be deferred to FY 1987.

CARDIAC SURGERY

We are very concerned with the VA Cardiac Surgery Programs because of the publicity received at the Miami VAMC.

Question: How does the mortality rate at VA open heart surgery programs compare with rates in community hospitals? Do you have any demographic data comparing VA's open heart surgery patients to patients in community hospitals? Would you please provide this for the record? Do you believe these patient differences explain the difference in mortality rates?

Answer: The mortality rates of cardiac surgery in VA programs compare favorably with those from community hospitals where that information has been made available, i.e., two non-VA hospitals in Miami, and with the published reports of mortality rates in New York State. In the case of the Miami hospital, one had higher and one had lower rates, but statistically they were equivalent.

No detailed comparative data are available for comparison. In general, community hospitals do not release such data.

We believe that many VA patients are higher risk patients than those in civilian community hospitals. Therefore, the mortality rates may be higher in some VA programs where these patients are accepted for surgery.

Question: What actions have you taken to implement changes in the VA cardiac surgery program?

Answer: We have formed an ad hoc committee to investigate the ethical questions of operating upon high risk patients, as well as other relevant topics such as what volume of cases should be required and how many and where our programs should be located. This committee first met in March and will hold other meetings in the future to deliberate these topics.

Question: Has the VA Consultant Committee recommended closing of any open heart surgery programs? What did you do about these programs?

Answer: Yes, in the past six years the Committee has recommended closure of seven programs. They have been closed for insufficient volume, high mortality or excessive costs in one case.

The programs that were recommended for closure were closed.

MAGNETIC RESONANCE SCANNING

Question: The VA highlights of October 11, 1984 indicated that the VA had issued purchase orders for magnetic resonance imaging type 1 devices.

The St. Louis VAMC 0.15 Tesla Resistence Scanner cost $880,000 the 1-5 Tesla super conducting imaging scanners for VAMC Boston and Richmond cost $1,451,150 each and the 2.0 Tesla spectroscopy scanner for VAMC San Francisco cost $230,000.

Would you please identify the facility costs to modify each of the hospitals to accommodate these scanners?

Answer: The cost estimate to modify the hospitals to accommodate these scanners are:

VAMC Richmond	$1,332,000
VAMC Boston	$1,700,000
VAMC San Francisco	$ 30,000

It should be pointed out that these siting costs are higher than normal for VAMC Boston and Richmond since these units were purchased to train other VA physicians and technicians. The siting cost for the unit at VAMC San Francisco is lower since this unit is a small bore animal research magnet.

Question: Would you also calculate the percent of the scanner purchase price that each of the facilities modifications represent?

Answer:

VAMC Boston	54%
VAMC Richmond	48%
VAMC San Francisco	12%

These percentages are based on the following estimated total project costs which includes cost of the equipment.

VAMC Boston	$3,151,150
VAMC Richmond	$2,783,150
VAMC San FRancisco	$ 260,000

Question: Would you compare the cost of a turn key MRI system purchase to the cost of the existing practice of equipment purchase and facility modification including magnetic shielding?

Answer: The Veterans Administration has not yet used the turn key method of construction in siting a Magnetic Resonance Imaging System so we are unable to give an accurate cost estimate. There are, however, a number of assumptions that can be made based on discussions of turn key purchases with several vendors.

The turn key method would be faster than our conventional method. This is a result ot the elimination of time for preliminary design and separate bidding procedures for the architectural engineer and the construction contractor. This timesaving of twelve to eighteen months would result in a cost savings equal to the inflation index.

The American Hospital Association recently published a guideline report on MRI. Siting estimates varied from $90 to $208 per square foot. The average cost was $149. The average cost per square foot to site the magnets for VAMC's Boston and Richmond is estimated to be $229. While it is not possible to make a direct comparison between the AHA study and the costs of these two somewhat specialized facilities, a rough estimate can be made that savings on an average facility of 6000 total square feet should exceed $400,000.

ROLE OF THE VAMC DIRECTOR

Question: P. L. 98-371 directs the VA in relation to major construction projects "that prior to the issuance of a bidding document for any construction contract for a project approved under this heading (including completion items), the director of the affected Veterans Administration medical facility must certify that the design of such a project is acceptable from a patient care standpoint". On Volume III, Page 13-1 of your FY 86 budget justification, you have gone out of your way to delete this provision of law in its entirety. Are you currently in conformance with this requirement of law?

Answer: The Veterans Administration is currently in conformance with this requirement of law. To implement this law a Department of Medicine and Surgery's Circular Number 10-85-4, subject "Medical Center Director's Certification on Major Construction Projects (Public Law 98-371)", was published and sent to the field January 11, 1985.

ROLE OF THE VAMC DIRECTOR

Question: P. L. 98-371 directs the VA in relation to major construction projects "that prior to the issuance of a bidding document for any construction contract for a project approved under this heading (including completion items), the director of the affected Veterans Administration medical facility must certify that the design of such a project is acceptable from a patient care standpoint". On Volume III, Page 13-1 of your FY 86 budget justification, you have gone out of your way to delete this provision of law in its entirety. It strikes me that this provision is quite modest in scope. I would think that any VA medical construction project should not only be readily certifiable as "acceptable" from a patient care standpoint, but indeed, should be certifiable as "outstanding". Why are you proposing deletion of this provision?

Answer: The Veterans Administration is proposing the deletion of this provision. The present law gives the Medical Center Director statutory authority which is the responsibility of the Administrator of Veterans Affairs under Title 38, U.S. Code, Section 210, Chapter 17, and the Chief Medical Director under Title 38, U.S. Code, Chapter 73. The same goals can be, and have been, accomplished by an internal procedure requiring the Medical Center Director to make this certification to the Chief Medical Director.

MEDICAL CARE STAFFING CRITERIA

In October of 1983, the Veterans Administration requested the National Academy of Sciences to determine the proper methodology to study physician productivity. Existing studies were insufficient to provide guidelines for internal staffing requirements within the Veterans Administration. The National Academy of Science methodology was to be completed in October of 1984.

Question: What is the status of the National Academy of Science's study? When will the VA transmit a copy to the Committee? Was the methodology acceptable to the Veterans Administration? If not, explain the deficiencies.

Answer: The VA has received and is reviewing a "final" draft of the study. We expect the study to be issued officially by NAS within the next two weeks. We will send a copy to the Committee as soon as the final study is cleared by the Administrator. The methodology recommended in the draft feasibility study appears acceptable, but the VA has not yet taken a final position on the methodology outlined and recommended in the draft study. We expect to provide some commentary to the Institute of Medicine, NAS, prior to the final report's issuance. However, we expect no significant changes to be made between this draft and the final report.

Question: What was the Veterans Administration's objective in requesting this study? How do you intend to pursue this line of research?

Answer: The Committee is aware that the Department of Medicine and Surgery is in its fourth year of a major initiative to improve the management of staffing and productivity of the Department's 192,000 employees. We have identified over 40 areas of concentration and we are working with industrial and management engineering techniques to study, measure, analyze and document a "standard number" of employees required to accomplish given work, versus the number actually assigned to those work centers. These "overstaffing" and "understaffing" levels are made known to VA medical center directors and other VA management officials, who then have opportunity to make adjustments where and as appropriate to "balance" staffing using these rational tools. Much of this work to develop staffing measures is unprecedented in the health care field, so a considerable developmental effort and investment of resources are required.

Several research investigations show that physicians' actions constitute a major determinant of the cost of health care. Some studies suggest more than 80% of the cost of care is determined by physicians' decisions. Also, the VA's 21,000 physicians constitute only 10.9% of total DM&S FTEE, but consume 23% of Departmental payroll costs. These facts justify efforts to analyze and better manage the physician resources available to the Department.

Because of physicians' special role in the management of medical care in DM&S, and their interrelationship to cost, it is important to accomplish this study through a highly accredited and reputable firm. We believe the Institute of Medicine is an appropriate body of outside experts, with the resources and influence necessary for such an unprecedented effort. We desire, therefore, to request the IOM to perform the major study. We are advised by IOM that a study of this nature would cost slightly less than $2 million.

Question: This is a relatively new research field. How was the National Academy of Science methodology judged? What weighed heavier, face validity or personal preference? What decision have you come to on the NAS methodology?

Answer: As stated above, we have not yet reached a final conclusion, but based on our review to date, we believe the recommended approach is acceptable. Once the study is finalized and published by IOM, it will be reviewed by all interested VA officials. Briefly, IOM is recommending the study concentrate on four work elements as physician staffing foundations: patient care; education and training; research; and administration/continuing education. The methodology itself will focus on developing the concept of "full-time physician equivalents," divided into specialty areas of medicine, surgery, psychiatry, rehabilitation, and "other," based on annualized workload demands aggregated at national, regional, district and facility levels. Physician needs are to be developed in ranges as opposed to point estimates. To the maximum extent possible, classic industrial engineering techniques will be relied on in the developmental effort, but the character and nature of physician work will add a dimension of difficulty not encountered previously, and may necessitate reliance on other techniques from the statistical sciences, or perhaps on some empirical observations. The study's continuing goal will be to instill the highest practicable degree of rationality to this effort, with minimum reliance on less measurable methods of building a staffing profile.

Question: Has the Veterans Administration circulated its findings about the NAS methodology internally? When will the Veterans Administration make its findings known to the Committee?

Answer: The NAS-IOM draft report is being reviewed at the staff level, which may necessitate minor changes to the final report. Key VA officials, and several Congressional committees will be provided copies of the final report soon--probably within two months.

Question: What is your timeframe from this point on? When do you plan to secure the second part of the study, which will determine the validity and reliability of the methodology?

Answer: Our original intent was to contract immediately with IOM, but no funds are available from FY '85 appropriations for this specific purpose. Assuming the study commences in FY 1986, IOM's study indicates a completion date in about three years.

QUESTIONS SUBMITTED BY SENATOR DOMENICI

Question: When does the VA anticipate the submission of a legislative package necessary to implement the proposed FY 1986 reforms:

Answer: We anticipate submitting the legislative packages to implement the proposed FY 1986 reforms shortly after the congressional recess.

Question: Has the VA prepared an analysis of the administrative requirements of implementing the intent of Third Party Reimbursement? Please outline the results of the analysis including projected collections.

Answer: The VA is currently analyzing the requirements associated with implementing a major third party reimbursement program. Final estimates, either for receipts or for costs, have not been settled. It is expected that such figures will be available in the near future.

Question: What impact will Third Party Reimbursement have on the demand for VA care?

Answer: As the impact of the third party initiative is essentially transparent to the patient, there is no expected impact on demand, pro or con.

VA HOUSING LOAN ORIGINATION FEE

The FY 1986 budget proposes to increase the VA Housing Loan origination fee. While some estimates suggest the Loan Guaranty Revolving Fund (LGRF) will achieve solvency without a increase in the origination fee, other estimates project fund deficits.

Question: In the absence of legislative action to increase the origination fee, does the VA anticipate the need for a FY 1986 Supplemental request? If a Supplemental is anticipated, what are the estimated resource requirements?

Answer: If the Congress does not enact the Administration's proposal to increase the fee to five percent, an appropriation of $404.6 million will be necessary to adequately fund the Loan Guaranty Program.

Question: For FY 1985, what percent of the property in the VA portfolio has been sold to date? What is the dollar amount of the collections generated by asset sales?

Answer: VA had 21,895 properties in inventory at the beginning of FY 1985. During the first five months of this fiscal year, VA has acquired 10,109 additional properties while selling 10,213. Expressed as a percentage VA has sold 32 percent of all properties on hand and acquired. VA has collected $382 million in asset sales through February of this fiscal year.

QUESTION SUBMITTED BY SENATOR ABDNOR

COST OF UPRIGHT HEADSTONES

Question: Will you please submit the five year cost estimate for the legislation passed in the House last year to permit the continued use of upright headstones in our National Cemeteries?

Answer: If passed this year, the five-year costs of this legislation are estimated to be $20.4 million, and 15 FTEE.

QUESTIONS SUBMITTED BY SENATOR BYRD

GRAFTON CEMETERY EXPANSION AT PRUNTYTOWN

Question: Mr. Walters, what is the latest status of the Grafton Cemetery expansion at Pruntytown, for which I secured an earmarking of $1.75 million in the reports accompanying the fiscal year 1984 and 1985 appropriations bills providing funding for the Veterans Administration?

Question: What are the significant events leading to the completion of this project. I am advised that the site may be ready for burials as early as September 1986, under the so-called "Fast-Track Burial System." Please elaborate on this concept.

Answer: The expansion of the Grafton National Cemetery is proceeding on schedule. The project schedule calls for completion of working drawings by December 1985, construction award in February 1986, and completion of the project in May 1987.

It is planned to have a "fast-track" area open for burials in September 1986. This concept allows for the development of an area for burials ahead of the actual construction completion date. It includes a roadway to the site and actual development of the site, but does not provide for committal shelters, administration building or other structures which are part of the total construction project.

CLARKSBURG VA MEDICAL CENTER CLINICAL ADDITION

Question: Mr. Walters, what is the latest status of the $21.4 million clinical addition for the Clarksburg VA Medical Center, for which appropriations were provided in fiscal year 1985?

Answer: The architectural design of this project is complete, and on February 6, 1985, we approved an award for working drawings. The project is on schedule and construction should begin in early 1986. The schedule for completion of construction is April 1988.

BECKLEY VA MEDICAL CENTER CLINICAL ADDITION AND ALTERATION

Question: What is the status of the $25 million clinical addition and alteration project for the Beckley VA Medical Center? What are the significant milestone events leading to the completion of this project?

Answer: Preliminary plans for this project have been completed and there is a new cost estimate of $15.3 million. The 1986 Budget was prepared within the overall context of a major effort to contain federal spending and, therefore, a number of projects planned for FY 1986 were not included. We anticipate that this project will be considered for inclusion in the FY 1987 Budget. Should this project be included in the design fund, working drawings could begin in 1986 and construction in 1987.

OTHER CONSTRUCTION PROJECTS

Question: What is the status and probable timetable of other VA construction projects contemplated for West Virginia, such as the $7.1 million Nursing Home Care Unit for Beckley and the $12 million replacement laundry building for Martinsburg?

Answer: Currently a project for the construction of a 120 bed NHCU is planned for 1988 at the VA Medical Center, Beckley, West Virginia. There are two major construction projects planned for the VA Medical Center, Huntington, West Virginia. There is a "Clinical Improvement Addition" planned for 1987 and a "Research Addition and "120 bed NHCU" planned for 1988. The only major construction project planned for VA Medical Center Martinsburg is a $5,200,000, laundry replacement. This project is currently undergoing a cost analysis to determine if it would be more cost effective for the VA to contract for these services. All of the tentative planning dates for the projects referenced above are, of course, subject to the availability of resources and nationwide priorities.

STAFFING AT THE HUNTINGTON VA MEDICAL CENTER

The Senate report accompanying the fiscal year 1985 HUD appropriation bill included language, incorporated at my request, directing the VA to determine what constitutes adequate levels of personnel resources at the VA medical centers affiliated with the five recently established medical schools activated by P.L. 92-541. One of the affected VA medical centers is located in Huntington, West Virginia. The Committee requested a report on this matter by January 1, 1985. However, I am advised that the draft report is still being reviewed at the VA. I am further informed that the report may advise that although the five affected medical centers, on average, may be receiving nearly adequate staffing, the Huntington VA medical center, in contrast, has not been allocated the necessary resources.

Question: What can you tell me about this matter, Mr. Walters?

Answer: The report on the adequacy of staffing at seven VA medical centers, including Hungtington, requested by the Senate Committee on

Appropriations tions Report 98-506, has been prepared and is being reviewed by the Office of Management and Budget. We expect to submit this report shortly.

In determining the adequacy of staffing at five of seven medical centers, the assigned task force used two sets of criteria-service-generated criteria (developed during the 1960's) and by Management Systems Service, Office of the ACMD for Administration, and based on State-of-the-Art Mamagement engineering techniques.

Using the service-generated criteria, the task force determined that the Huntington VA medical Center was 24.6% below its projected staffing needs. Applying the more sophisticated staffing guidelines to twenty-three key programs and services, the task force found that the Huntington facility was 22.3% below its level of "earned FTEE" i.e., what the facility workload and activity should have based on the developed staffing guidelines.

The task force then combined the results of the two staffing approaches and concluded that the Huntington, VAMC was understaffed when compared to the national average for all VAMC's and showed the severest understaffed situation of the five VAMC's which were included in the study.

The likelihood of meeting the staffing standards at VAMC Huntington and other VA medical centers is highly improbable because of budgetary restraints. However, consistent with study results, a site visit will be made to VAMC Huntington to explore possible avenues of assistance.

There is a need for acute in-patient psychiatric care in West Virginia. For example, veterans needing this care in the Huntington area, are sent approximately 250 miles away for treatment in Salem, Virginia. This does not seem a particulary good arrangement for the patient at a time when he might need the support of his family and friends. It is my understanding that the Huntington Veterans Administration Mecial Center has requested the allocation of 15 to 30 beds for an in-patient psychiatric care unit.

I hope that you will look favorably on that request.

Question: Would you please provide for the record, the current status of this request by the Huntington VA medical center?

Answer: The establishment of an in-patient psychiatric unit has been recommended for approval by the MEDIPP process and has been included in the requirements for the Advanced Planning Fund project: "Clinical addition (Phase 2)." If finally approved, the unit will be activated in FY 1990 following completion of construction of the new addition.

DEPARTMENT OF VETERANS BENEFITS

I note that you are planning to reduce employment in the Department of Veterans Benefits by 17 percent in 1986-1988 and consolidate benefit processing from 59 regional offices into 3 processing centers.

West Virginia has a Veterans Administration Regional Office at Huntington, West Virginia.

Question: Would you provide for the record, the number of employees by grade and function that are currently at that regional office; and the number of employees by grade and function that would be affected by your proposed consolidation.

Answer: The number of employees by grade and function that were assigned to the Huntington Regional Office on December 31, 1984 are shown in the table below:

GS	Executive Direction	Veterans Services	Adjudication	Loan Guaranty	VR&C	Office Services	TOTAL
2						1	1
3			5			2	7
4		1	4	1		9	15
5		2	2	3	2	5	14
6			2			8	10
7	1	1				1	3
8	1	2					3
9		8	11			1	20
10		7		1		1	9
11		2	5	2	2	1	12
12	2	2	6	1	2	1	14
13		1	2	1	1		5
14	1		1				2
15	1						1
Total	6	26	38	9	7	30	116

We are not in a position to know the impact of consolidation, should it occur. When the Department's plan for modernizing operations is completed, we will be able to respond in greater detail.

Question: Do you anticipate any increase in the length of time that it would take to apply and reach a determination on benefits and if not, what steps are you taking to insure that delays in processing will not occur?

Answer: Consolidation should it occur, would be a part of an overall VA modernization program to improve service to the veteran. Therefore, no degradation of service would result.

Question: I further note from your budget justification, that there would be no loss of personal services to veterans. Would you detail for the record, the grade and function ~~of~~ personnel at each veterans assistance location in West Virginia?

Answer: Each veterans assistance location is serviced by a GS 10 Veterans Benefits Counselor. Huntington, Clarksburg and Beckley are served on a part-time basis. Martinsburg however, has a full-time counselor assigned.

VIETNAM VETERANS READJUSTMENT COUNSELING CENTERS

In FY 1985, funding was provided to establish additional Vietnam veterans Readjustment Counseling Centers. Contract authority was retained to allow for instances where Vietnam veterans were in rural or remote areas from these centers.

Question: The availability of counseling to Vietnam veterans continues to be a matter of concern for many West Virginians. Do you see a need for additional counseling centers at this time?

Answer: The Agency does not see a need for additional counseling centers at this time, especially in light of the 52 new Vet Centers which are at this time being implemented. However, the Agency plans to establish a one-person Vet Center Satellite in Charleston and a two-person counseling office in Martinsburg. Both offices should be open by the summer of 1985.

Question: Do you anticipate a need for additional contract centers in rural areas?

Answer: The total number of contract providers currently is approximately 540. The Agency's position is that this number of providers is sufficient. According to the needs of specific localities, on an ongoing basis certain contracts are not renewed when it is determined that need has declined, and at other locations, new contracts may be issued to respond to a previously unmet need. This process can be utilized, within existing resources, to respond to the needs of specific localities. There are currently twelve organizations providing contracted readjustment counseling in West Virginia.

QUESTIONS SUBMITTED BY SENATOR CHILES

DEPARTMENT OF VETERANS BENEFITS

Administrator Walters, on February 1 you transmitted a letter to Senator Stennis which discussed a proposed Veterans Administration plan to consolidate functions of the Department of Veterans Benefits (DVB) now carried out in 59 regional offices. Under the plan, these functions would be carried out in 3 processing centers. Personnel would be reduced by more than 2,300 over a three-year period. On its surface, this plan appears to have merit. However, I am concerned that we do not have any of the detailed information upon which the Congress could make an informed judgment on this proposal. We need to make sure that nothing in this plan compromises the fairness and timeliness of service that veterans and their families receive from the VA.

As you know, 38 USC 210 (b), requires that the VA present to the Congress a detailed plan and justification before undertaking any reorganization of the size and scope presented in the budget.

Question: Since your letter does not indicate which 3 cities will become the sites for the processing centers, and which 59 office will lose activities and personnel, would you specify the locations and the numbers of personnel affected by this plan?

Answer: No sites for the proposed processing centers have been determined. The President's 1986 budget identified 624 FTEE associated with consolidation. However, I met with the Deputy Director of OMB on February 11, 1985, to discuss the DVB consolidation requirement. OMB agreed to extend the timeframe for submission of a plan to implement consolidation until the modernization issue has been fully examined. A task force has been formed to "aggressively examine DVB's operation in light of the Agency's modernization goal and the principles on which it is based."

Question: I am concerned that vital face to face contact with veterans and their families not be lost as a result of this plan. What specific activities will be transferred? Do any of these involve direct dealings with veterans and their families?

Answer: No decision has been made on what activities will be affected, should consolidation be accomplished. I can assure you however, that no services to the veterans or their families will be diminished.

Question: How can the Congress be assured that services to veterans are not being reduced?

Answer: As I have indicated, Senator, no action taken by this Administration will diminish services to the veteran or his dependents.

Question: Any proposal to consolidate processing on such a significant basis would seem to require that a carefully developed ADP system be in place. Please tell us about the status of the ADP plan which would be part of this reorganization.

Answer: On February 15, 1985, I issued a management directive for modernizing automation and telecommunications systems in the VA. The directive proposes better service to the veteran through modernization and consists of six key guidelines:

1. Proposed changes are to be assessed from the vantage point of the veteran;

2. Each employee must have appropriate on-line access to those data bases needed for his/her job;

3. Systems and equipment must be designed for easy use by nontechnical personnel;

4. VA staff must be relieved of paperwork burdens;

5. Capitalize on experience of others in our planning efforts; and

6. Organizational roles must be better defined.

This is an agency-wide directive to be implemented by all Departments and Staff Offices.

Question: As you know, 38 USC 210(b), requires that the VA present to the Congress a detailed plan and justification before undertaking any reorganization of the size and scope presented in the budget. Do you consider that your letter of February 1 meets this statutory requirement?

Answer: The letter of February 1, 1985, which reported the DVB consolidation plan to appropriate committees of the Congress was timely and did contain some detail and justification for this proposal. Although extensive details were not given, the report did outline the framework of the proposal and explain its basic purpose and justification. Additional detail can and will be provided to the Committees, as the report letter itself indicated, to facilitate adequate scrutiny of all aspects of the proposal.

Question: In light of the lack of specifics in your February letter, can we be assured that no action will be taken on this plan until a much more specific and detailed proposal is given to the Congress?

Answer: No final decision has been made as to the specific DVB consolidation proposal. It has been agreed that the Veterans Administration will develop a plan for modernizing its entire operations, and that we will consider various efficiency alternatives, one of which may be DVB consolidation. The DVB effort has just begun however, and, when it is completed, a decision will be made as to the best course of action to be taken concerning DVB. I want to assure you that we will, as always, work closely with the Congress through our oversight Committees, and with veterans organizations to achieve a consensus before proceeding.

VA HEALTH CARE FACILITIES IN FLORIDA

Two studies were conducted by the VA to consider the health care delivery system in Florida. The first study, "A Thirty Year Study of the Needs of Veterans in Florida," mandated by Public Law 97-101, documented the need for 1,251 additional VA hospital beds in Florida to meet veteran population demand as projected to 1995. A second study, "A Report on Future Bed Need and Potential Sites for New VA Hospitals in Florida," completed in June, 1983 analyzed hospital bed need in Florida by 1995 and detailed the VA criteria which led to the selection of the Palm Beach County site as the first of four new Florida locations for medical centers.

Question: What is the current status of the Medical Center in Palm Beach? Are funds required in this fiscal year to move forward with the project? Are funds included in the Administration's FY 86 Budget Request?

Answer: We are currently investigating a number of sites in the county and have hired an architect/engineer to prepare an Environmental Impact Statement (EIS) on several sites. This project was initially funded in FY 1984 for Advance Planning. No funds were requested in the FY 1986 Budget Request for this project as it is still in the early advance planning stage.

Question: The Administration has approved development of plans for a new 470 bed hospital and 240 bed nursing home care unit in Brevard County. Is the Brevard County Medical Center under consideration for advance planning in FY 86? Have funds been requested? What funding would be necessary?

Answer: The administration has not given final approval to constructing a new VA hospital in Brevard County but this project is under consideration for inclusion in the Advance Planning Fund (APF) in FY 1986. As you are aware, the APF provides "seed money" for advance development of future construction projects. The magnitude cost estimate for the Brevard County Medical Center is $140,000,000. Advance Planning Fund for this project would be approximately $2.4 million.

Question: What is the most recent status of the VA's consideration of utilizing an existing hospital in Mobile, Alabama instead of constructing a new facility in northwest Florida, as was recommended by VA planners? When will a final decision be made on this matter.

Answer: Medical District No. 10, which has the planning responsibility for veterans residing in the Southern Alabama and Northwest Florida areas, has been instructed to continue to analyze the health care needs of this area, including Mobile Alabama. The medical district has completed the required analyses and has made recommendations which are currently being reviewed.

Question: The study also mentioned the long-range need for a 215-bed hospital and a 120-bed nursing home care unit in Lee County. Please comment on the status of planning for this facility.

Answer: In concert with the two studies mentioned, Medical District 12 Planning Board has recommended a 215-bed hospital and 240 NHCU bed facility be built in Lee County. Presently, the VA has not established a schedule for a facility in the Lee County, since the recommendations are still under consideration.

Question: Please provide a ranking of Florida's VA Medical Centers relative to the workloads of all 172 VA Medical Centers in terms of number of inpatients treated, outpatient visits and doctor/patient ratios. For outpatient statistics please include workload accomplished by satellite clinics.

Answer: The following table provides the values of the requested statistics as well as their ranks (in descending order) for each of the five Florida medical centers.

	Patients Treated		Patients/ Physicians		OP Visits		Visits/ Physicians	
VAMC	#	Rank	#	Rank	#	Rank	#	Rank
Tampa	12,249	13	73.5	130	225,648	18	1353.6	113
Miami	14,043	12	102.4	77	306,550	4	2234.3	23
Gainesville	10,236	29	86.8	122	138,758	48	1176.9	140
Bay Pines	10,522	26	117.0	72	178,008	29	1980.1	42
Lake City	7,873	58	289.4	3	26,952	147	990.9	122

Question: Please provide the status of providing an Outpatient Clinic in Daytona Beach, Florida. What funding need is anticipated in FY 86? Is this reflected in the Administration's Budget Request?

Answer: Currently, Daytona Beach Outpatient Clinic is planned for activation in January 1986. The original budget for the clinic was submitted for funding in FY 85 with annualization of resources in FY 86. Equipment, nonrecurring activation costs, part of the total staffing, and other recurring costs, were budgeted in FY 85 with annualization of staffing costs, and other recurring expenses in FY 86. This is reflected in the Administration's Budget request.

VA HEALTH CARE REALLOCATION

Question: It is my understanding that there is a quarterly procedure for reviewing situations in emerging needs of VA medical centers. Funding needs and requests are made by hospital administrators to the Regional Medical District Directors who then, if possible, reallocate funds within his district to meet those demands. I have been told by the VA that the Medical District Director can appeal to the Department of Medicine & Surgery Resources Allocation Committee for consideration of a request that funds be reallocated from another medical district.

Has this procedure been invoked in either Medical District Number 10 or Number 12 in my state? Have, in fact, funds appropriated by Congress for one medical district been reallocated to another medical district that experienced increased demands?

Answer: Fiscal year operational funds are not appropriated at the Medical District level as indicated in the question above. After the medical care appropriation is apportioned to the Administrator, the Department of Medicine and Surgery allocates funds on a Regional basis between six (6) Regions. Yes, funding adjustments have been made by the Department to reallocate resources into Medical Districts 10 and 12 in order to partially meet the increased workload demands in those Districts.

The Resource Allocation Committee referred to in the question reviews requests of an emergent nature and for which the Regional Director cannot adequately meet the resource requirement. This committee does not reallocate funds between Districts.

FLORIDA'S PART-TIME RESIDENTS

Question: Along with its increase in permanent veteran residents, Florida also experiences a seasonal influx of winter veteran residents who permanently reside in other states.

In this age of computer technology, has any thought been given to establishing some sort of "billing" system where a Florida VA Medical Facility that provides hospitalization and/or treatment to a non-resident of the State can receive reimbursement for this expense from the facility in the Medical District where the veteran permanently resides.

Answer: No. A mechanism for reimbursement of Expenses specifically generated to capture dual residence veterans has not been developed and for good reason.

The workload that a veteran generates as an outpatient or inpatient is accumulated by the facility in which he is cared for as part of their workload statistics. These actual workloads are presently used as one basis to adjust facility budgets within available resources. An example would assume that a Florida facility provides 80,000 outpatient visits to Florida citizens and 20,000 seasonal visits to dual residence veterans. When the budget for that facility is being developed it will recognize the total number of outpatient visits recorded, 100,000, and ignore the state citizenship of the veterans who generated the visits.

To deal with increased demands, we are attempting a process of reallocation so that veterans will have equal access to care throughout the nation. The reallocation of existing resources is being addressed through our decentralized program planning effort, known as Medical District Initiated Program Planning -MEDIPP- and the 30-year Florida study which was mandated by the Senate Appropriations Committee in Fiscal Year 1982, to deal with the long-term effect on VA health care of the increasing veteran population in the state of Florida. We expect to resolve this disparity of resources throughout the country over the next several years. It will only be after we have a clear understanding of what is transpiring nationwide with respect to the veteran population, and their migration patterns, that we will be in a position to more directly deal with the resource allocation to those areas with the greatest need.

Question: Is there a consistent VA policy for providing travel reimbursement to a veteran who received treatment/services from a VA Medical Facility other than the one within the Medical District in which he permanently resides?

Answer: Medical District considerations are irrelevant to travel reimbursement. When a patient is eligible and travel is authorized, payments will be made for travel to the closest facility to the patient's home that can provide the medical treatment. Patients may, of course, visit any VA facility that they wish to, but travel reimbursement will be limited to the amount that would have been paid for travel to the closest clinically appropriate facility.

FLORIDA VA NATIONAL CEMETERY

Question: Please provide the status of development of the VA National Cemetery in Florida (Withlacoochee National Forest). What is the projected timeframe for completion? What are the funding needs for the cemetery in FY 86? Are these funds requested in the Administration's Budget Request?

Answer: The construction award is scheduled for September 1986, with completion expected in September 1987. Funds totaling $6.5 million were included in the FY 1986 budget request for development of the burial site, administration/service buildings, and related entrance gate, roads and utilities.

It is anticipated that staffing of the cemetery will begin in September/October 1986, therefore administrative/operating costs were not requested in the FY 1986 budget.

QUESTIONS SUBMITTED BY SENATOR LEAHY

VA HOUSING LOAN ORIGINATION FEE

Mr. Walters, I have received a letter from a realtor in Vermont (Orests Valsangiacomo) in which he states that raising the points on a VA mortgage from one to five will effectively kill the VA program.

Question: Do you agree?

Answer: No, we do not agree with this statement. The basic features of the GI loan program will remain intact, i.e., no money down, fully assumable loans, and no prepayment penalty.

Question: Do you support this recommendation?

Answer: Yes, I support increasing the funding fee to 5 percent in order to reduce the deficit in the Loan Guaranty Revolving Fund.

APPROPRIATION REQUEST

Your 1986 budget, as presented to Congress, is down $123 million compared to 1985. Your efforts at economy are to be applauded.

Unfortunately, you included an asterisk in your budget--in fact, a $400 million asterisk.

You note that if the proposal to increase the loan origination fee on VA mortgages from one to five percent is not adopted, we will have to appropriate $400 million to cover that cost.

Question: If it became clear that legislative authority to raise the points is not granted by the time we are ready to mark-up, will the President submit a request for that $400 million?

Answer: If the Congress does not take action to increase the fee to five percent, VA will need an appropriation of $404.6 million to adequately fund the program. Without additional funding, VA cannot honor commitments made to lenders under the guaranty agreement or pay ongoing expenses associated with the maintenance and disposition of acquired properties.

Question: At the present time, the VA cannot collect from private health insurers for emergency care provided for non-service connected disabilities in VA facilities.

According to GAO, VA could have recovered between $100 and $280 million if it had the power to collect for these services.

Why have you not submitted legislation which has the potential of making such large savings?

Answer: The Veterans Administration currently has the authority and the duty, by virtue of section 611(b), title 38, United States Code, to charge for emergency medical care which the Agency may furnish, as a humanitarian service, to a person who would otherwise be ineligible for care.

In most of those cases we are able to collect the charges when the individual has a private health insurance policy with a clause excluding coverage for care provided by the VA. The exclusionary clauses are usually only applied in cases when the patient is a veteran otherwise eligible for VA care. Most of the individuals receiving emergency VA care on a humanitarian basis are not otherwise eligible for VA care. For example, the individual may not be a veteran. In those cases, insurance companies generally will pay for care notwithstanding the existence of an exclusionary clause.

The GAO report you allude to concluded that the VA could have recovered at least $98 million to $284 million from private health insurance in FY 1982 for medical care, emergency or otherwise, provided for nonservice-connected disabilities but for exclusionary clauses contained in most health insurance policies.

We are preparing proposed legislation to authorize recovery of the costs of such care and prohibit exclusionary clauses which preclude payment to the Agency. We anticipate that the proposal will be submitted to the Congress in the very near future.

Question: Your budget includes a new legislation proposal to means test medical care for those aged 65 and above.

Does the budget you have submitted assume that these changes have been made?

Answer: The funding consequences of the means test have not been included in the 1986 budget submission.

Question: Will the total request have to be raised if this legislation changing health care eligibility is not enacted?

Answer: The total request will not have to be raised if this legislation is not enacted.

Mr. Walters, 95 percent of your program is composed of compensation, pensions and medical programs. About 2.5 percent is construction, and the final 2.5 percent is for general operating expenses.

Question: How much of your budget is legally established entitlements that we must fund?

Answer: Legally, only the benefits programs are entitlements. They total $15.6 billion, or 59.3 percent of VA's 1986 appropriation request. The medical programs are not legally considered an entitlement. The basis for access to medical benefits is generally at the discretion of the Administrator, subject to the availability of VA treatment facilities as explained in the excerpts below from Title 38 of the U.S. Code.

Chapter 17--Hospital, Nursing Home, Domiciliary, and Medical Care

Subchapter II--Hospital, Nursing Home, or Domiciliary Care and Medical Treatment

Section 610. Eligibility for hospital, nursing home and domiciliary care.

(a) The Administrator, within the limits of Veterans Administration facilities, may furnish hospital care or nursing home care which the Administrator determines is needed to--

(1)(A) any veteran for a service-connected disability; or (B) any veteran for a non-service-connected disability if such veteran is unable to defray the expenses of necessary hospital or nursing home care;

(2) a veteran whose discharge or release from the active military, naval or air service was for a disability incurred or aggravated in line of duty;

(3) a person who is in receipt of, or but for the receipt of retirement pay would be entitled to, disability compensation;

(4) a veteran who is a former prisoner of war;

(5) a veteran who meets the conditions of subsection (e) of this section; and

(6) any veteran for a non-service-connected disability if such veteran is sixty-five years of age or older. (Amended P.L. 87-583, section 1; P.L. 89-358, section 8; P.L. 91-500, section 4; P.L. 93-82, section 102(1), (2); P.L. 94-581, sections 202(d)(2), 210 (1)(A), (B); P.L. 97-37, section 5 (a) P.L. 97-72, section 102(a)(1).)

(b) The Administrator, within the limits of Veterans Administration facilities, may furnish domiciliary care to--

(1) a veteran who was discharged or released from the active military, naval or air service for a disability incurred or aggravated in line of duty, or a person who is in receipt of disability compensation, when such person is suffering from a permanent disability or tuberculosis or neuropsychiatric ailment and is incapacitated from earning a living and has no adequate means of support; and

(2) a veteran who is in need of domiciliary care if such veteran is unable to defray the expenses of necessary domiciliary care. (Amended P.L. 89-358, section 8; P.L. 94-581, sections 202(d)(2), 210 (1)(B), (C).) P.L. 97-72, section 102(a)(1).)

(c) While any veteran is receiving hospital care or nursing home care in any Veterans Administration facility, the Administrator may, within the limits of Veterans Administration facilities, furnish medical services to correct or treat any non-service-connected disability of such veteran, in addition to treatment incident to the disability for which such veteran is hospitalized, if the veteran is willing, and the Administrator finds such services to be reasonably necessary to protect the health of such veteran. The Administrator may furnish dental services and treatment, and related dental appliances, under this subsection for a non-service-connected dental condition or disability of a veteran only (1) to the extent that the Administrator determines that the dental facilities of the Veterans Administration to be used to furnish such services, treatment, or appliances are not needed to furnish services, treatment, or appliances for dental conditions or disabilities described in section 612(b) of this title, or (2) if (A) such non-service-connected dental condition or disability is associated with or aggravating a disability for which such veteran is receiving hospital care, or (B) a compelling medical reason or dental emergency requires furnishing dental services, treatment, or appliances (excluding the furnishing of such services, treatment, or appliances of a routine nature) to such veteran during the period of hospitalization under this section. (Added P.L. 89-785, section 304; amended P.L. 93-82, section 102(3); P.L. 94-581, section 210 (a)(1)(B); P.L. 96-22, section 102(a).)

(d) In no case may nursing home care be furnished in a hospital not under the direct jurisdiction of the Administrator except as provided in section 620 of this title. (Added P.L. 93-82, section 102(4); P.L. 94-581, section 202 (d)(4).)

(e)(1)(A) Subject to paragraphs (2) and (3) of this subsection, a veteran--

(i) who served on active duty in the Republic of Vietnam during the Vietnam era, and

(ii) who the Administrator finds may have been exposed during such service to dioxin or was exposed during such service to a toxic substance found in a herbicide or defoliant used in connection with military purposes during such era,

may be furnished hospital care or nursing home care under subsection (a)(5) of this section for any disability, not withstanding that there is insufficient medical evidence to conclude that such disability may be associated with such exposure.

(B) Subject to paragraphs (2) and (3) of this subsection, a veteran who the Administrator finds was exposed while serving on active duty to ionizing radiation from the detonation of a nuclear device in connection with such veteran's participation in the test of such a device or with the American occupation of Hiroshima and Nagasaki, Japan, during the period beginning on September 11, 1945, and ending on July 1, 1946, may be furnished hospital care or nursing home care under subsection (a)(5) of this section for any disability, not withstanding that there is insufficient medical evidence to conclude that such disability may be associated with such exposure.

(2) Hospital and nursing home care may not be provided under subsection (a)(5) of this section with respect to a disability that is found, in accordance with guidelines issued by the Chief Medical Director, to have resulted from a cause other than an exposure described in subparagraph A or B of paragraph (1) of this subsection.

(3) Hospital and nursing home care and medical services may not be provided under or by virtue of subsection (a)(5) of this section after the end of the one year period beginning on the date the Administrator submits to the appropriate committees of the Congress the first report required by section 307(b)(2) of the Veterans Health Programs Extension and Improvement Act of 1979 (Public Law 96-151; 93 Stat. 1098). (Added P.L. 97-72, section 102, (a)(2).)

MORATORIUM ON NEW CONSTRUCTION STARTS

Question: The President has insisted, in the Department of Housing and Urban Development's Budget, that there be a two year moratorium on the Construction of incremental assisted housing units. Your budget includes $261 million for three major new veterans' health facilities. The moratorium in assisted housing is defended purely on the basis of budget restraint. Should there be a similar moratorium on new construction starts at VA?

Answer: The VA health care delivery system, to provide the highest quality of care, must keep pace with modern medicine. This requires the maintenance of existing space and new construction to accomodate changing workloads and changes in medical care modalities. To reduce the resources needed to maintain the existing structures and to keep pace with the systemwide facility space needs results in a deterioration of the facilities' ability to provide the best quality health care.

While the budget does contain a request for $261 million under the Replacement/Modernization category, this should not be construed as representing "new construction starts." All three projects have as a major component the replacement/modernization of existing structures. New capacity will be provided to meet projected future demand for inpatient, outpatient and nursing home care but this is primarily to bring these facilities up to the present standards for modern medical care. The other categories of projects in the construction budget also represent this mix of renovation/modernization and "new" facilities, whose need is predicated on the above premise.

WHY SO MUCH TEXAS?

Question: On page 66 of your Budget in Brief, you name by site the nine new major construction projects for FY 1986. Four of these are in Texas. Why?

Answer: There are a variety of factors considered in determining if a project is included in the Agency budget request. These include the extent of a project's development; the space and technical deficiencies existing at a particular medical center, including those relating to life safety codes; the compatibility with the long range mission as identified through MEDIPP; and the priority ranking. Since geographical area is not considered in this process, it is purely coincidental that of the nine projects on page 66 of the Budget in Brief, four are located in the State of Texas. A total of 31 major construction projects were included in the FY 1986 budget request.

HOMELESS SHELTERS/MEDICAL

Question: Last year two VA doctors visited a homeless shelter operated by the Community for Creative Non-Violence in Washington,

They examined a small number of veterans at the facility who had medical problems. I have been told that they sent eight people to VA hospitals in cabs because they were in such bad shape.

Are you willing to send VA medical personnel to homeless shelters, if these shelters contain significant numbers of veterans?

Answer: The Department has not established a policy of specific programs to VA medical personnel to visit shelters, however, some of our personnel (principally social workers) have visited in response to specific local shelter requests, as well as a part of an overall VA effort to ensure that veterans who may be homeless become aware of the availability of VA programs and benefits. As a general rule, our staffing is not sufficient to permit any major program where VA medical facilities are always available to eligible veterans -- including those who may be homeless -- to evaluate their health problems.

DEPARTMENT OF VETERANS BENEFITS

Question: The Secretary of Health and Human Services has been asking the VA to sign an interagency agreement in which it would agree to cooperate with the Department of Health and Human Services in addressing the problems of homeless veterans. Has the VA signed the agreement? If not, why not?

Answer: The Veterans Administration received the original request from the Department of Health and Human Services which asked for our participation on the Federal Task Force on the Homeless. The VA has been a willing and active participant on the Task Force since that time. That participation has come from the Office of the Associate Deputy Administrator for Congressional and Intergovernmental Affairs. The VA is unaware of a request by DHHS that we be a signatory on an interagency agreement.

Question: The President's Task Force on Hunger, in its January 1984 report, stated that "a disturbingly large proportion of the homeless, perhaps one-third, are veterans." What steps has the VA taken in response to this report?

Answer: The Department of Veterans Benefits has not received the subject report. Nevertheless, our regional offices have ongoing relationships with the social service programs, shelters and other public and private activities supporting the homeless. Likewise, there is a close relationship between the regional offices and corresponding medical centers so that referral for emergent or suggested medical care as well as claims assistance is attended to as appropriate. Recently, our regional offices have canvassed their respective jurisdictions to assure we are fully aware of all established shelters for the homeless and that liaison contact has been made with the shelter officials.

A number of our offices have worked closely with these shelter officials or social service agencies. While we have not gathered empirical data to support or refute the contention that "perhaps one third" of the homeless are veterans, our field stations report they find the percentage far lower. Several of the stations who are more active in outreach programs have estimated the veteran percentage to be 10%.

Question: Whenever there are stories in the newspapers on the homeless, there are reports that some of these homeless persons are veterans. The President's Task Force on Hunger and the Homeless concluded that "Many homeless may be eligible for VA benefits." (p. 27)

There is a developing consensus that the deinstitutionalization of mental patients has increased the homeless population.

Has the VA ever done a follow-up study of a representative sample of veterans released from VA psychiatric care to determine what percentage, if any, are homeless?

If not, why not?

What would be the cost of conducting such a study?

Answer: The VA has not undertaken any organized study to determine if previously hospitalized psychiatric patients become homeless.

Question: If not, why not?

Answer: The VA's approach to the treatment of psychiatric problems attempts to concentrate on providing the necessary community, social and medical supports to maintain patients acceptably outside the hospital institutional setting. The question seems to infer that some of VA's long-term psychiatric population might be part of the homeless group, but we cannot confirm such an inference.

Question: What would be the cost of conducting such a study?

Answer: As a rough estimate, such a study by a management consultant would cost perhaps as much as $1 million, assuming the focus would be national and would involve data collection from all parts of the country, would include records reviews, evaluation by physicians, social workers, community care staff, and inquiries and questionnaires to shelters, missions, police, etc.

SUBCOMMITTEE RECESS

Senator LAUTENBERG. We stand in recess until Wednesday, April 24, at 10 a.m., in the same room. At that time we will hear from FEMA and the EPA.

Thank you all very much for your presentation.

Mr. WALTERS. Thank you, Senator.

[Whereupon, at 12:03 p.m. Thursday, March 28, the subcommittee was recessed, to reconvene at 10 a.m. Wednesday, April 24.]

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